Chemical Engineering Progress

FEBRUARY 1956

GETTING INTO ROCKET PROPELLANT MANUFACTURE

evaporator manufacturers reveal how to get

MORE EVAPORATION

for LESS MONEY

WHAT TO DO ABOUT SELECTIVE SERVICE

Executive Order Sets Pattern

PLUS Markets for Epoxies • Frequency Response in Process Control • Analog Computers
Little Known Facts about Porous Media • Liquid-Metal Handling • Sealed Centrifugals
Guide to Separation Processes • Direct Conversion to Electricity • Special News on Atomic Situation

process know-how for LOWER ALIPHATIC

ALCOHOLS

CH_3OH
C_2H_5OH
iC_3H_7OH
nC_4H_9OH

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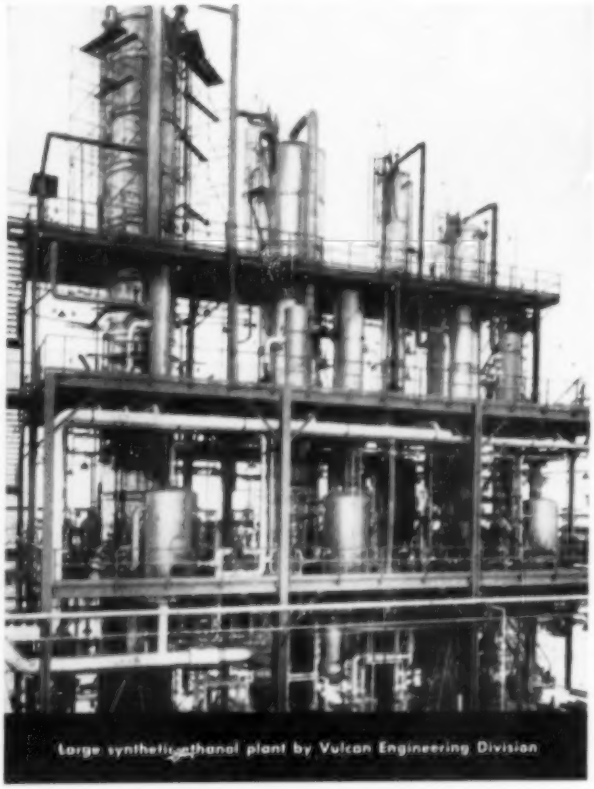
PURIFICATION
DEHYDRATION • RECOVERY

Vulcan's accumulated experience with lower aliphatic alcohols goes back over 50 years — covers hundreds of installations throughout this country and abroad — establishes Vulcan as the leading designer and constructor of plants and units for production and recovery of alcohols.



Large synthetic ethanol plant by Vulcan Engineering Division

- ★ Production of METHANOL by the Vulcan-Inventa Synthesis Process.
- ★ Production of ETHANOL by fermentation or by synthesis from ethylene.
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- ★ Production of N-BUTANOL by fermentation.
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Chemical Engineering Progress

what's in this issue

February, 1956 • Volume 52, No. 2

Drugs—Up and down / 47
Trends—Evidence is increasing that the entire drug industry cannot be regarded as in a state of dynamic growth.

C.E.P. SPECIAL FEATURE

More evaporation for less money

Cost factors in evaporator design / 45–F
W. D. Kohlins & H. P. Englander—A host of often-ignored factors are described as exerting major influence on cost of evaporation facilities.

Selection and application of evaporator equipment / 49–F
M. M. Coston & E. E. Lindsey—Although selection of optimum type of evaporator is empirically based on previous experience, the selection procedure and data requirements described are useful aids in simplifying the job.

Using the epoxy resins / 53–F
C. V. Wittenwyler—Whether your interest in epoxies is for use in your own process plant, incorporation in a product, or possible manufacture to meet the expanding demand, the chances are this resume may provide just the information needed.

Heat and flow characteristics of porous media / 57–F
J. F. Coppage & A. L. London—Wire screening and lead shot were used to simulate the porous media for a series of experiments intended to provide badly needed data for the process equipment designer.

Frequency response analysis in process control (Part 2) / 64–F
Ernest F. Johnson—In his earlier article (C.E.P. August, 1955), author Johnson related frequency response to the imposition of a sustained sinusoidal variation in some property of an inlet stream of a process. This response offers a simple means for automatic control. How such control systems can be devised is the subject of this second paper.

Use of electric analogs in reactor design / 69–F
J. B. Roberts & J. A. Beutler—For the past four years, DuPont's Engineering Research Laboratories have been

(Continued on page 5) ⟶

Cover design by Milton Wynne Associates

departmental features

Letters to the editor / 6 • Noted and quoted / 28 • Marginal notes / 36
Opinion and comment / 43F • Data Service / 65 • Candidates for Membership / 92
News from local sections / 94 • Future meetings / 98 • People / 100
Classified / 104 • News and notes of A.I.Ch.E. / 112

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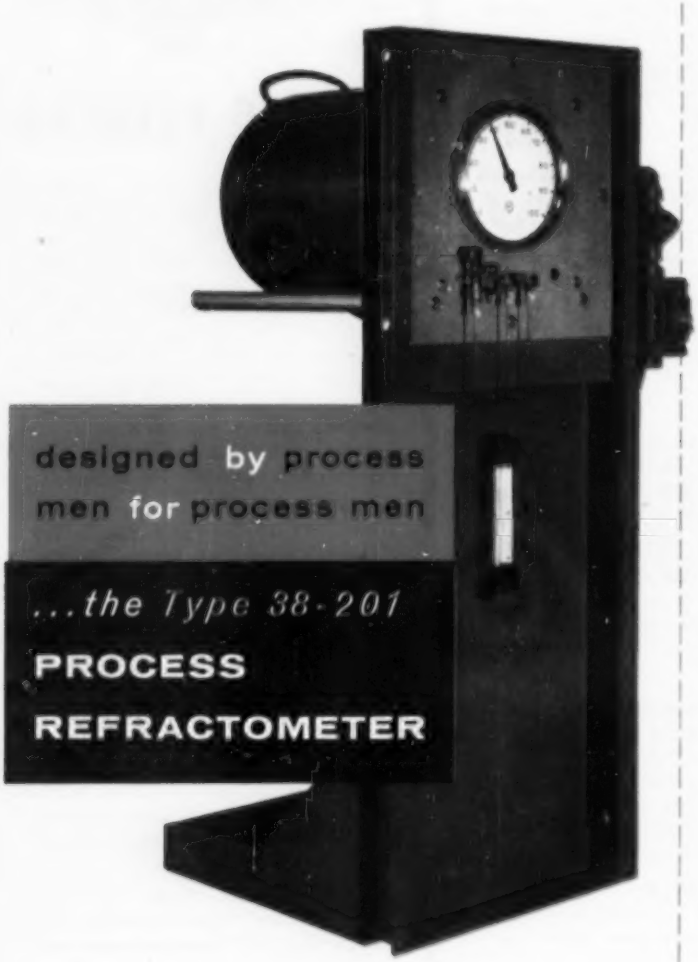
Here's above all a *practical* process monitor and controller, which can materially lower your costs and raise both throughput and quality. For the complete story of the 38-201 Process Refractometer, write today for Bulletin CEC-1839 X19.



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. . . the 38-201 measures the difference in refractive index between a liquid standard and a flowing liquid sample obtained *directly from a process line*. Refractive index is related to density and thus is able to provide a direct indication of relative composition changes in binary mixtures. When the process stream is complex, a binary mixture is approximated when all but one or two key compounds remain reasonably constant.

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RUGGED CONSTRUCTION—explosion-proof design permits use anywhere, even out-of-doors.

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FREEDOM FROM MAINTENANCE—basic design simplicity keeps unit operating without attention for long periods. If repairs are required, all electronic and optical assemblies are easily reached, and can be replaced quickly with standardized spare units.

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what's in this issue

(Continued from page 3)

using, with considerable success, an installation of analog computers for solution of a considerable variety of reactor performance problems.

Liquid-metal handling / 75–F
S. G. Bauer—Know-how in designing and operating a heat transfer system employing liquid metal heat transfer agents has to do with leak tightness, purging, pumping, and other factors described in this practical article.

Chart for selecting equipment for separation processes / 78–F
C. M. Nicholls—The degree of radioactivity to be expected governs many factors in the planning of processing facilities to be so exposed. In this simple chart, which is from a Geneva paper, a general indication is obtained.

Facilities for development of double-base propellants / 79–F
A. T. Camp, C. H. Carlton, Q. Elliott, & J. H. Wiegand—Rocket propellants may have to be manufactured in enormous quantities for stockpiling or for use in wartime.

The hermetic centrifugal separator / 83–F
F. E. Sullivan—The hermetic centrifugal separator operates with mechanical seals on both inlet and outlet, to enable use of hydraulic pressures of 150 lb./sq.in. Aeration is avoided, which permits handling of emulsifiable mixtures.

Where you stand in selective service deferment / 49
The President's recent signing of executive orders to implement Public Law 305 now gives you a basis for proceeding with an application for deferment—if you can meet the new exemption provisions.

Private industry and nuclear fuel reprocessing / 50
How the recent A.E.C. policy of practical subsidy and access to information may make it possible for your firm to get started in this field of great future potential.

What the process industries are doing / 52
This month's Industrial News features another shale oil pilot plant in Colorado, using Swedish process.

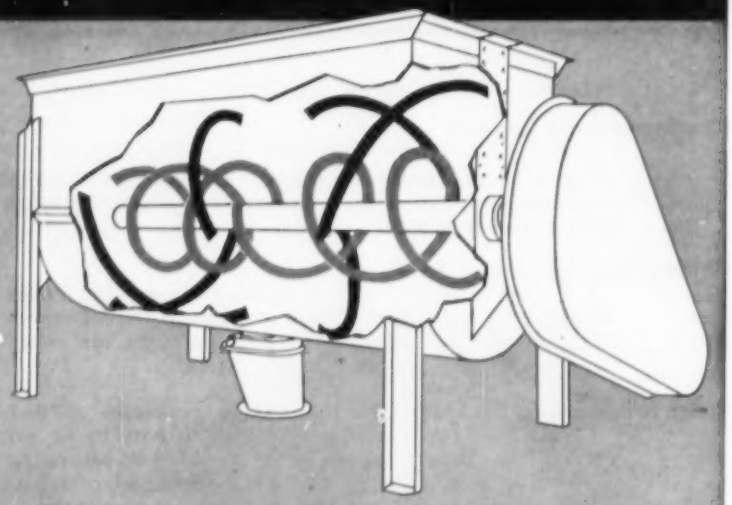
New Orleans—scene of May national meeting / 55
Survey of non-technical aspects of a fascinating locale.

Atomic batteries await low-cost materials / 60-61
E. G. Linder, P. Rappaport, & J. J. Loferski—The radioactive byproducts from nuclear piles may yield economic beta-emitters capable of energizing semiconductor-type "batteries."

Solvay's new H_2O_2 plant uses novel process / 80
Direct oxidation chemical process to supply needs for expanding newsprint industry.

Salary survey of rocky mountain chemical engineers / 90
Climate, beauty of surroundings, and bounteous living compensate for lower salaries.

FOR CONTINUOUS
OR BATCH OPERATIONS



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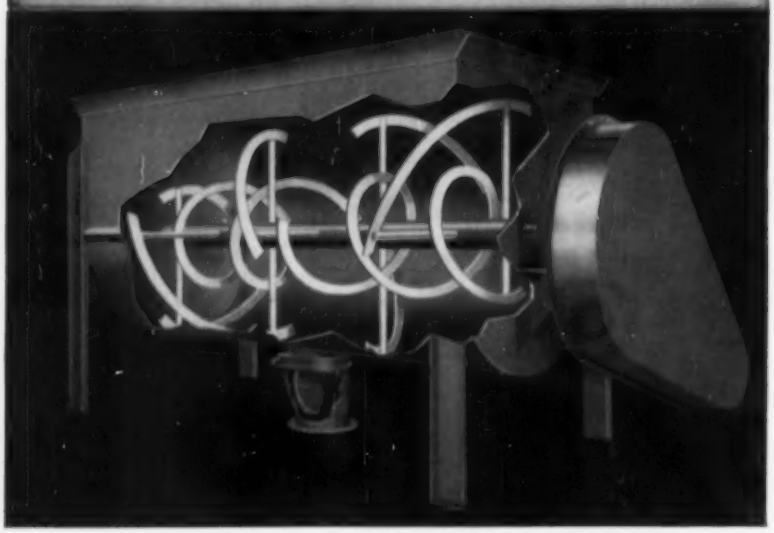
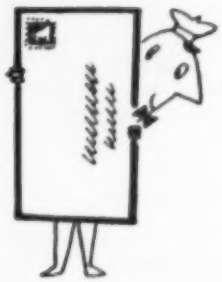


LETTERS TO THE EDITOR



Heat Transfer Division?

There is currently before the membership of the Institute the question: should the Institute have a Heat Transfer Division? I would like to present a more or less detailed statement on the issues involved and the advantages to be expected.

At the recent Detroit meeting, fifty-five members of the Institute signified their desire to have a Heat Transfer Division by signing a petition or division membership card. Judging from past interest in heat transfer symposia held at Atlantic City, St. Louis, and Louisville, one would expect several hundred to join a division. The assembled group at Detroit elected W. W. Akers, E. C. Ashton, Jr., S. W. Churchill, D. Q. Kern and D. L. Katz as a steering and nominating committee.

How many members of the Institute work in the field of designing and providing service to heat transfer equipment? Last year the writer had the privilege of giving lectures in seven cities on the subject of heat transfer. More than 400 engineers, the majority with a chemical background, attended. From this sampling of industry it seems fair to estimate that more than 800 chemical engineers are directly connected with work in the field of heat transfer. When adding an average of two faculty members per school or 200 more from the academic area, one can state with confidence that a minimum of 1,000 chemical engineers would have a direct interest in the activities of a heat transfer division.

Is heat transfer a subject of decreasing interest? Certainly not from the view of engineers in industry who are seeking ways to reduce initial and maintenance costs of heat transfer equipment. Many problems are arising in the nuclear field of heat transfer under extreme conditions of flux or temperature. The applications of fluid mechanics and analytical procedures to heat transfer problems are yielding new insights to special problems. Liquid metals as heat transfer agents present new prob-

(*Continued on page* 12)

Presenting the

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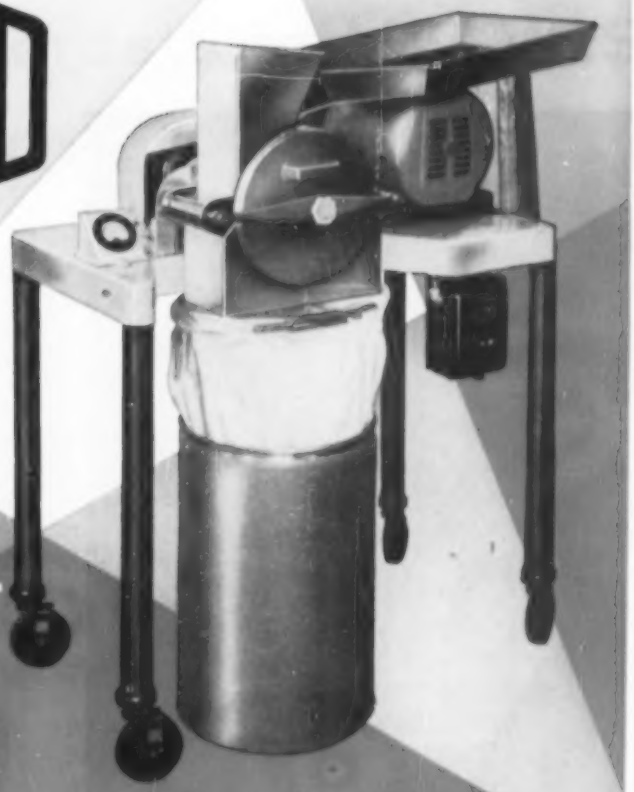

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This new unit, which provides precise particle control in the 4 to 20 mesh range, is light, yet durable. It is easily assembled and disassembled, permitting quick changes from one product to another with complete freedom from spoilage or contamination. It can also be readily adjusted for speedy changes in particle sizing.

Its ease of thorough cleaning and reassembly makes the MIKRO-Multi-D ideal as a utility unit for many industries, but particularly in the food and drug fields. A test on your own product in the MIKRO Laboratory may provide a solution to your grinding problems.

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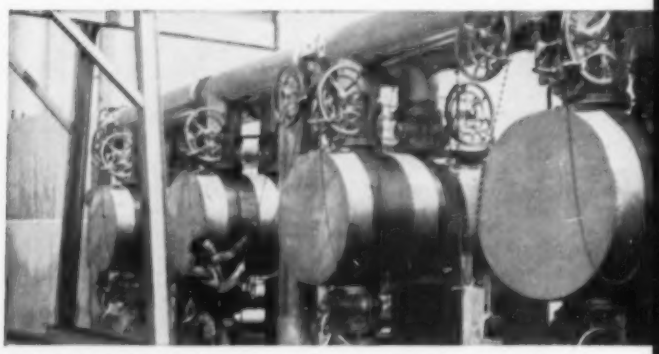
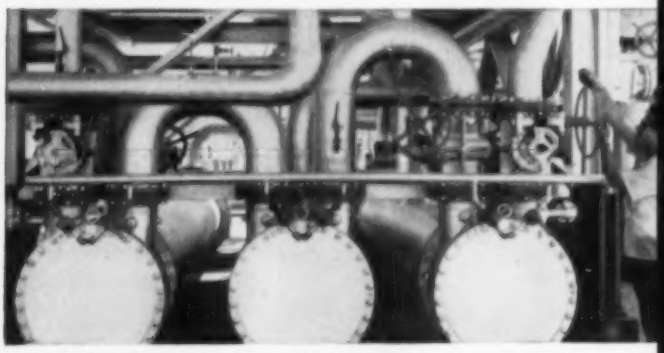
Break Production

PRECISE CONTROL on antibiotic processing at this pharmaceutical plant is assured by the fast, smooth quarter-turn operation of Rockwell-Nordstrom valves.



VERSATILE Rockwell-Nordstrom valves can be used in any position for flow in any direction. Ideal for chain-wheel or extension operating like the heat exchanger shown above.



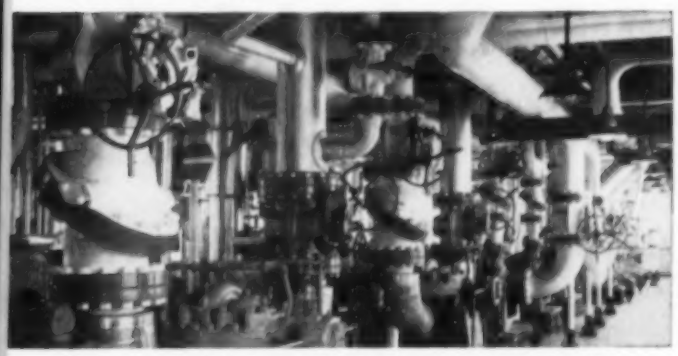
COMPACT Rockwell-Nordstrom valves on the gas coolers above have no stem assemblies or bonnet cavities to take up vital space. Space and weight savings mean real economy of designing and investment.

DEPENDABLE, LEAKPROOF Rockwell-Nordstrom valves cost no more, often less, than ordinary valves—but they assure *absolute reliability* on even the most critical service.

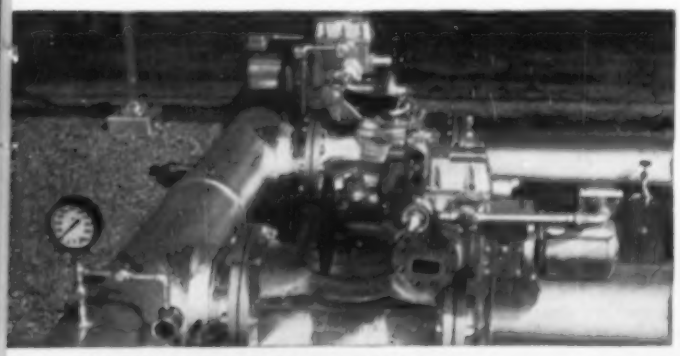
Bottlenecks

ROCKWELL-Nordstrom VALVES Keep Every Line On Stream

AT A GLANCE, you can tell whether a Rockwell-Nordstrom valve is open or closed. Costly, often dangerous guesswork and old-fashioned "feeling" a valve are eliminated.



BIG . . . BUT FAST. Every Rockwell-Nordstrom valve is fully opened or fully closed in one quarter-turn. On gear operated valves, this means operation is two to five times faster.



FOR POWER OPERATION, Rockwell-Nordstrom valves assure dependability and economy because simpler and less costly actuators are required for quarter-turn operation, and lubricant keeps them "ready to go."

For forty years, process engineers have insured better quality control and mechanical performance, greater safety, and lowest maintenance costs with Rockwell-Nordstrom chemical valves. They have been *proven* on every service from the earliest refineries to today's exacting demands of precise flow control in automatic chemical and processing plants. The facts speak for themselves . . . everywhere you use Rockwell-Nordstrom valves they will assure you greater "on stream" dependability at lower cost than any other valve you have ever used.

Look at these installation photographs for just a few of the reasons why Rockwell-Nordstrom valves can help you break production bottlenecks. Rockwell Manufacturing Company, Pittsburgh 8, Pa.

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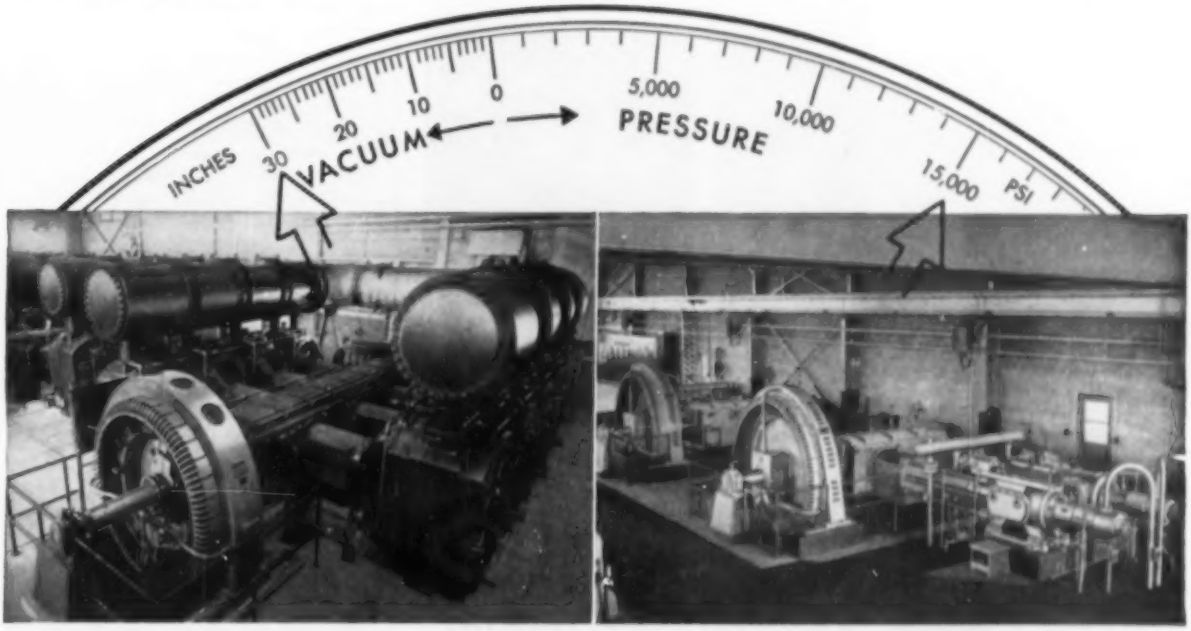

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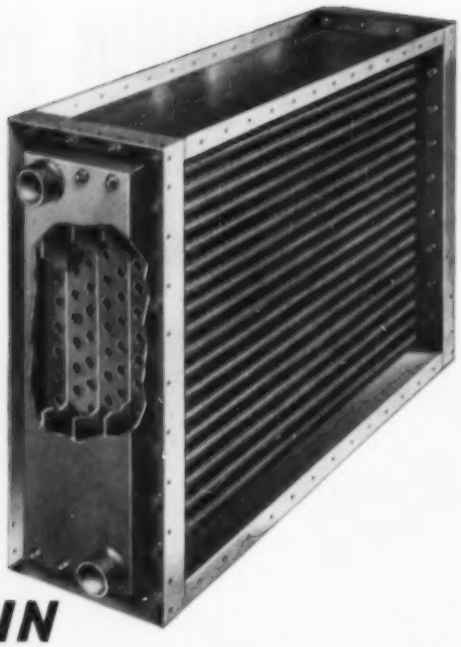

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LETTERS TO THE EDITOR

(Continued from page 6)

lems and require different techniques in experimentation and design. A total of eighty-three papers on heat transfer were presented at Institute meetings during the past five years and forty-five papers were published on that subject during the past three years.

How is the subject of heat transfer covered in the Institute now? The Program Committee is composed of eight divisions of interest: Operations A, Unit Operations B, Process, Kinetics, Equipment, Fundamentals, Commercial and Nuclear Energy. Unit Operations A is described as "Diffusional, mass transfer, fluid dynamics, and the like" and includes heat transfer. This division of interest under R. L. Pigford handled the joint program with A.S.M.E. on heat transfer at Louisville.

Everyone agrees that it would be fine for more members of the Institute to take an active part in its affairs. At present, three or four members of the Program Committee in the Unit Operations A group which handles heat transfer are active in the field of heat transfer and no doubt give the subject some thought in connection with their duties on the Program Committee. With a Division there would be seven members of the executive committee plus some eight members of the program committee or a total of fifteen persons taking part in developing programs on heat transfer.

The Institute has an Equipment Testing Procedure Committee with a subcommittee on Heat Exchangers. This activity would find considerable support from a Division.

A Heat Transfer Division will permit more contact and exchange of ideas between people interested in the subject. There is special need for contact between the academic and industrial people, and evaluation of research needs. Engineers other than chemical will be drawn into programs and divisional efforts. In turn, the Institute will have a designated group to represent it at such cooperative efforts as the Heat Transfer Conference now being organized by the Heat Transfer Division of the A.S.M.E.

The Institute will grow over the years ahead. The organization of Divisions from time to time along clearly defined areas of interest is a way by which the Institute can grow and maintain effective service in programs, publications, and professional matters.

Providing that the Program Committee and Council approve the proposed organization of the Heat Transfer Division the steering and nominating committee will

(Continued on page 16)

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GAP/R Modular Components give remarkable flexibility of structure and application
They adapt winningly to every size of project and budget, and to all operating speeds

COMPARE MODEL MK

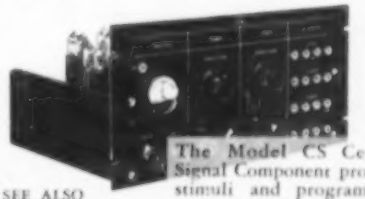
The Model HK Operational Manifold offers 10 amplifiers for analog calculations of great variety. Very rapid to connect and to use, this versatile unit is a computing center in itself.

COMPARE MODEL RS

The Model RK Regulated Power Supply employs premium transformers and inductors, plus a high-stability regulating circuit. Capacity of this Supply is sufficient for 4 of the above Model HK.

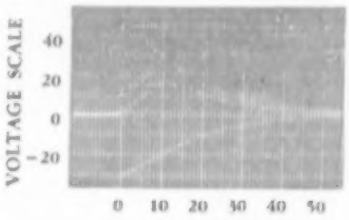
The Model K2-W Operational Amplifier is an octal-based plug-in unit which will serve as nucleus for accurate feedback functions. It has differential inputs, high DC gain, and useful bandwidth over 100 KC. Other models include the K2-X, which puts out ± 100 V and more power.

The Model K2-P Stabilizing Amplifier, used in tandem with the above, provides long term DC stability measured in microvolts. It installs directly in the HK Manifold or in other environments. We also manufacture dozens of other useful plug-in units in this unique package.



SEE ALSO MODEL CR BELOW

The Model CS Central Signal Component provides stimuli and programming commands for automatic repetitive computing. It sets initial conditions, and checks all calibrations.



ELECTRONIC GRAPH PAPER

For repetitive Analog solutions, this method of display enables simultaneous plotting, to high precision, of many concurrent variables. Calibration is automatic for time and voltage, and is proof against all oscillographic errors.

For normal time-scale purposes, a variation of this method is directly applicable. Known best for High Speed, GAP/R methods are actually *Pan-celerative.*

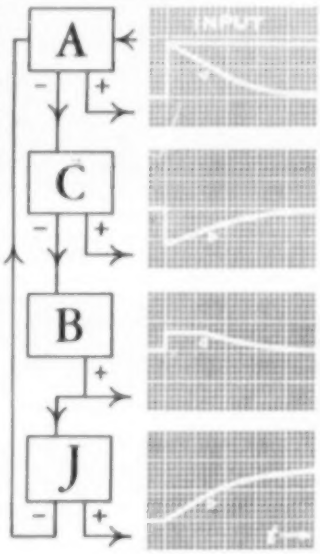
THE K3 SERIES OF COMPUTING COMPONENTS

The Model K3-A Adding Component accepts from one to 4 input voltages, and supplies both plus and minus their instantaneous sum. An additive constant may be set in manually. All signal inputs and outputs are at the front, and power is simply plugged in at the rear. At the right is shown a utilizing system.

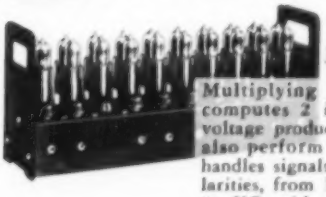
The Model K3-C Coefficient Component multiplies its input voltage by an adjustable constant, and gives outputs which are positive and negative versions of the instantaneous product. The scale shows unity (the most likely scale-factor) at the center, and sets readily down to zero and up to infinity.

The Model K3-B Limiting Component permits the input voltage to be passed on directly to the output whenever the input is within adjustable positive and negative bounds, but otherwise holds the output fixedly at the bound last exceeded. Such nonlinearities are readily analyzed with these handy tools.

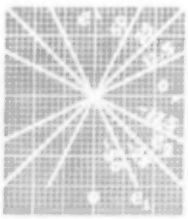
The Model K3-J Integrating Component computes plus and minus the time integral of the input, at selected rates. An input is available for clamping, to set the starting point. This unit serves, like our others, for fast or slow operation. In this same modular form, we offer 10 other fundamental types.

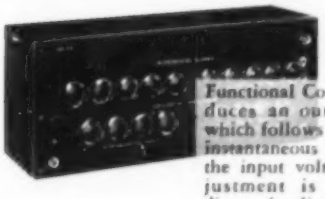


The Model CR Central Response Component accepts timing data from Model CS (above), and up to 8 signals for display; it generates the calibrated graphical display (as shown) for any 'scope.

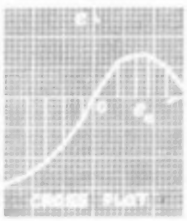


Model MU Multiplying Component computes 2 independent voltage products, and will also perform division. It handles signals of both polarities, from DC to above 50 KC, with accuracies to ½% or better.





Model FF Functional Component produces an output voltage which follows an adjustable instantaneous function of the input voltage. The adjustment is simple and direct. Applications abound for nonlinear problems.



GAP/R STANDARD products are too numerous for a single page. Included are accessories to fulfill all your analog needs.

SPECIAL equipment may be engineered for new or unusual applications.

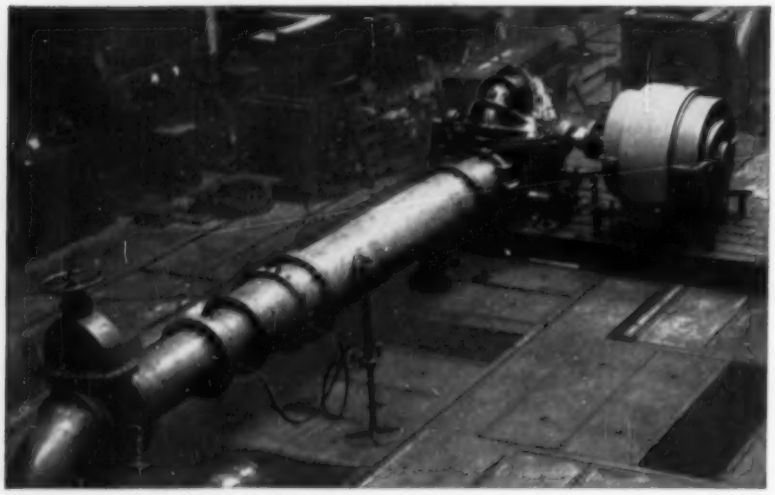
ADVICE is available on how our methods may be applied to your problems. Our staff is experienced and knowledgeable and cooperative.

COMPLETE RACK ASSEMBLIES

George A. Philbrick Researches, Inc., 230 Congress St., Boston 10, Mass.

Keep your eye on WORTHINGTON

Pump research primes pump progress



TEST STAND CAPACITY UP TO 100,000 GPM is provided at Worthington's Harrison plant *(above)*. Built over a man-made half-acre lake, the test stand is used as a production tool to check pumps from fractional horsepower up. This flexibility comes in handy—in one line alone Worthington can put together 60,000 different standard pumps out of 650 parts in six standardized sets of liquid ends.

DIRECTING PUMP TEST OPERATIONS from central control room *(left)* where special measuring instruments speed collection of performance data. Worthington pump specialists can afford to be objective in considering your pump application problem. They select from the most complete line of pumps offered by any manufacturer.

We have a lot of experience at Worthington—more than 114 years of it—and we're picking up more all the time.

But technology advances every day. Each step forward brings with it new and unsolved pumping problems. That's why Worthington's research and development program is continuous. That's also why we like to work with you during planning to get the jump on problems before they reach the costly stage.

Experts for every problem

For your day-to-day pumping problems, our sales engineers are thoroughly trained in pump applications in every field, and can usually supply the right answer fast. Naturally, for the really tough ones, our staff engineers back them up with all the equipment and facilities of our shops and laboratory. In addition, factory-trained troubleshooters are available to cope with any problem that may arise in the field.

From cat-cracker to atom-cracker

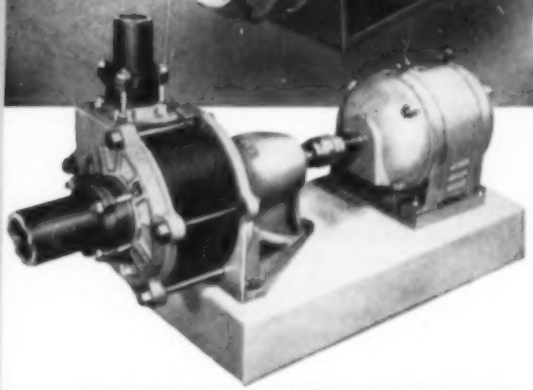
Our specialists, covering all major industries, work as a team. Together, they bring to bear on any problem a vast store of experience. They've successfully solved pumping problems and helped pioneer new developments in public works, atomic energy applications, the oil industry, and the chemical industry—to name a few.

So keep your eye on Worthington; we probably have a money-saving answer to your pumping problems. C-51

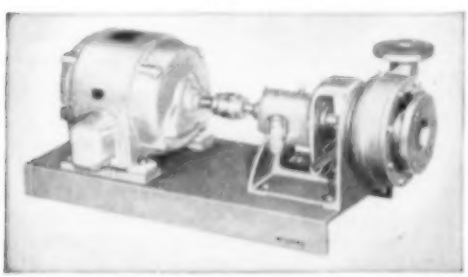
WORLD'S FIRST ATOMIC-POWERED SUBMARINE, *NAUTILUS*, undergoing sea trials. In atomic development since 1941, Worthington recently built special engine room equipment for both atomic submarines, *Nautilus* and *Sea Wolf*. Worthington continues to figure prominently in supplying this new field of atomic energy, keeping pace with its new and rapidly changing requirements.

EUTECTIC CASTING, used in making standard Worthington pumps, frees engineer from casting restrictions. Formerly, design of impeller and diffuser blades had to allow hand withdrawal from fragile sand core. Eutectic casting uses a low-melting-point alloy to form blades, melting this alloy out during baking. This permits design flexibility for maximum hydraulic performance.

VITALITY OF WORTHINGTON RESEARCH PROGRAM is shown by the more than 300 articles in the technical press during the past five years by Worthington people. This flood of informative technical literature not only reflects our ability to keep pace with the changing hydraulic requirements for modern pumps, but also highlights the important contributions by Worthington to the knowledge of pumps.



FAMOUS KARBATE* NON-METALLIC CHEMICAL PUMP, made of impervious graphite by National Carbon Company. Now you'll be able to buy this pump from Worthington. Karbate pumps include motor-mounted (close-coupled) and frame-mounted units with capacities ranging from 5 to 1500 gpm at heads to 110 feet at conventional motor speeds.



WORTHITE TYPE CNG CENTRIFUGAL CHEMICAL PUMP. Super-stainless Worthite provides best all-round metallic corrosion resistance in a standard pump. Manufactured in 27 standard sizes, it assures you of complete hydraulic coverage up to heads of 235 feet and capacities of 2500 gallons per minute. Worthite type CNG pumps are available with standard stuffing boxes, with Teflon seal cage arranged for independent cooling liquid, or with external mechanical seal.

Now Worthington offers you the widest standard corrosion-resistant pump line

as Karbate* impervious graphite supplements Worthite

Worthington Corporation is now marketing Karbate brand centrifugal pumps, manufactured by National Carbon Company, a Division of Union Carbide and Carbon Corporation, in addition to our Worthite centrifugal chemical pumps.

In Karbate pumps, parts in contact with the liquid pumped are made of impervious graphite, making the pumps applicable for many corrosive services where conventional metals or alloys are unsuitable.

Worthite pumps already form the broadest line of metallic centrifugal pumps in the industry. This coverage is now completed by the addition of the non-metallic Karbate Brand Impervious Graphite Pumps. You'll find Worthite and Karbate pumps your best bet for virtually 100 percent of corrosive applications.

Worthite is a high-nickel, high-chromium, molybdenum alloy steel, with 0.07 percent maximum carbon content. It is stainless and its stabilizing elements tend to prevent intergranular corrosion.

Write today for copies of bulletins W-350-B14A and W-350-B18 describing in detail Worthite and Karbate centrifugal chemical pumps. Worthington Corporation, Standard Pump Division, Harrison, New Jersey. C.S.I.A

*Reg. Trademark of Union Carbide and Carbon Corporation.

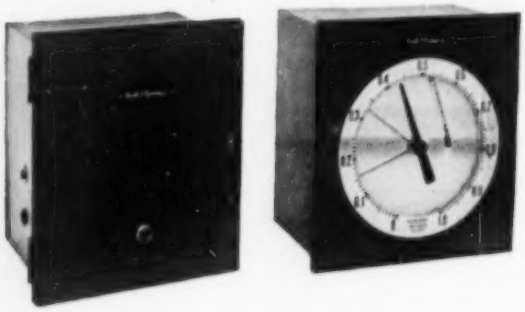
WORTHINGTON

THE WORLD'S BROADEST LINE
ASSURES YOU THE RIGHT PUMP FOR EVERY JOB

CENTRIFUGAL • ROTARY • STEAM POWER • VERTICAL TURBINE

NEW SAVINGS in your operations

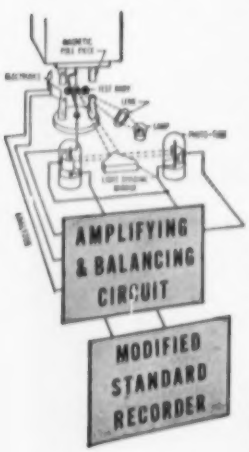
with Arnold O. Beckman OXYGEN ANALYZERS



Pictured is the Model G2 Recording Analyzer—finest for precise oxygen measurement.

ON OPERATIONS LIKE THESE... MAKE SAVINGS LIKE THESE

PROCESSING AIR LIQUIFRACTION AND PRODUCTION OF HIGH PURITY GASES	*Better product quality with minimum oxygen or air contamination*
SAFETY PRODUCTION OF HYDROGEN, ACETYLENE, ETC.	*Control explosive atmospheres, reduce fire risks, minimize plant and personnel hazards*
PRODUCT PROTECTION RESIN KETTLES, COLOR PIGMENTS, PRODUCT STORAGE, ETC.	*Reduce oxidation, maintain product standards with controlled purge systems*



Unique Operating Principle

The various applications highlighted above are only a few of the many ways Arnold O. Beckman Oxygen Analyzers—industry's great new profit builders—are being used by progressive operators to boost profits, cut costs.

These are the *only* oxygen analyzers that *continuously* measure process streams by an advanced magnetic principle that provides *direct physical measurement of the oxygen itself*—not of some secondary relationship.

Heart of the unit, as illustrated, is a dumbbell-shaped test body suspended in a magnetic field. Sample gas surrounding this test body causes it to rotate in the field, depending upon the oxygen content of the gas. The movement of a light beam, reflected by a small mirror on the test body, is measured by simple electronic circuits... and the result indicated directly on a conventional recorder or indicator. It's simple, positive, accurate!

No chemicals—filaments—catalysts cams—complicated mechanical parts!

FEATURES OF THE G2

Many ranges: Full scale ranges 0-0.1%, 0-0.5%, 0-1% O_2 and others for low O_2 concentrations. Ranges 90-100%, 95-100% O_2, etc., for high O_2 concentrations.

Multi-Ranges: Any instrument may be supplied with two or more ranges.

***Note:** For ranges wider than 0-5% O_2, ask about the Model F3 Analyzer.*

***Send for Helpful Free Literature** which describes this unique operating principle in detail—explains its many advantages and applications. When writing, outline your particular operations—we'll gladly supply specific information.*

Ask For Data File 15A-26

Arnold O. Beckman INC
Instruments for Science and Industry
1020 MISSION STREET
SOUTH PASADENA, CALIFORNIA

LETTERS TO THE EDITOR

(*Continued from page 12*)

submit a slate of candidates for each office to all members who have expressed interest in the Division. Any member who wishes to be added to this list should write to Professor Stuart W. Churchill, department of chemical & metallurgical engineering, University of Michigan, 2028 E. Engineering Building, Ann Arbor, Michigan, before March 15.

DONALD L. KATZ

Ann Arbor, Michigan

Teach-the-Teacher Idea Grows

Because of your interest in the "Teach-the-Teachers" schools, an idea advanced by Ken Kobe some years ago, I am writing to tell you about the school held [December 9, 1955] at the Alloys Plant of Reynolds Metals Company, Sheffield, Alabama.

Negotiations to get Reynolds to sponsor a school on "The Aluminum Industry" were started about three years ago. Last spring Reynolds finally decided that such a program could be put on and specific plans were started.

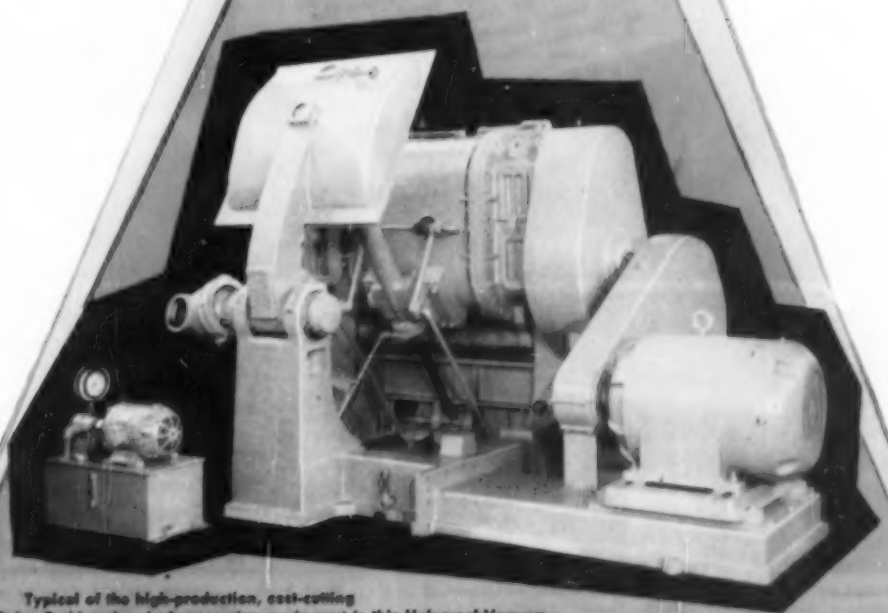
I believe you will be interested to know that this is the third school that the Department of Chemical Engineering [University of Mississippi] has arranged and that we helped in getting a fourth school developed:

1. **Ammonia Technology—Sponsored by Tennessee Valley Authority, Wilson Dam, Alabama (November 9, 1951).**
2. **Applications of Catalysis in Industry—Sponsored jointly by the Girdler Corporation of Louisville, Kentucky, and the Tennessee Valley Authority, Wilson Dam, Alabama (November 21, 1952).**
3. **The Aluminum Industry—Sponsored by the Reynolds Metals Company, Sheffield, Alabama (December 9, 1955).**
4. **The Vegetable Oil Industry—Sponsored jointly by the Buckeye Cellulose Corporation and the Humko Cotton Oil Company of Memphis, Tennessee (November 13, 1953). (Arranged by the chemistry departments at Memphis State College and Southwestern College at Memphis.)**

As you can see from the above we have to date emphasized schools on a process or industry basis rather than on the unit operations basis, this plan being more suitable for this section of the country. Furthermore we have always included our chemistry brethren in the schools. A total of twenty-eight chemistry and chemical engineering teachers from the following schools have signified their intention to attend the Aluminum Industry School: Vanderbilt University Memphis State College, Southwestern Col-

(*Continued on page 22*)

B-P
mixers
designed and
built for
maximum efficiency
regardless
of product



Typical of the high-production, cost-cutting Baker Perkins chemical processing equipment is this Universal Vacuum Mixer, size 15 TWBM. Working capacity 100 gallons; total 175 gallons. Constructed of Stainless Steel, jacketed for 125 psi heating or cooling.

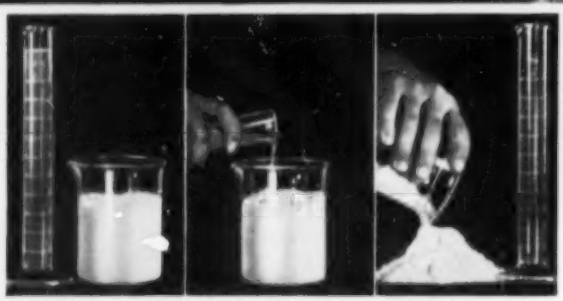
BAKER PERKINS INC.

Chemical Machinery Division • Saginaw, Michigan

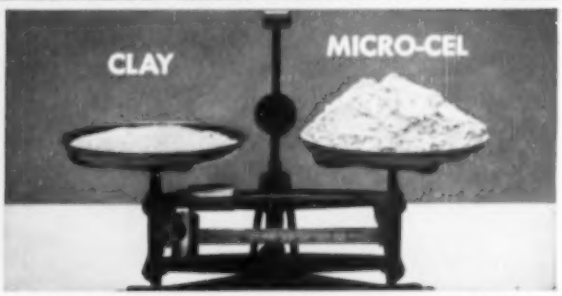
326

Announcing... a new line of synthetic

CLAY
The powder that flows like a liquid
Micro-Cel (as compared with clay in photo) will greatly improve the flowability of many products . . . maintains its free-flow properties even under the most adverse storage conditions.



Absorbs up to 6 times its weight in water—Micro-Cel remains a free-flowing powder even after absorbing more than twice its own weight of liquid.



High bulk . . . loose weight density as low as 5 lb. per cu. ft.—Micro-Cel "fluffs up" any compound with a minimum addition.

JOHNS-MANVILLE PRODUCTS JM **Johns-Manville MICRO**

calcium silicates developed by Johns-Manville Research

MICRO-CEL...

Check its different combination of properties . . . it may hold the key to lower costs and product improvements in your process formulations.

Johns-Manville's new Micro-Cel line can produce many desirable effects as the following examples illustrate.

Absorption of Liquids—Micro-Cel will absorb 1 to 2½ times its weight of liquids and still remain a free-flowing powder.

Uniform Dry Dispersion—Different Micro-Cel grades with particle sizes as low as .02 microns and particles of rounded to spherical shape provide fast, uniform blending without segregation.

Viscosity Control—Various degrees of viscosity up to a paste or semi-solid can be achieved by adding relatively small quantities of Micro-Cel.

Anti-caking Agent—Micro-Cel's high absorption and fine particle size of less than 0.1 micron effectively control caking of deliquescent products and insure flowability even after prolonged storage.

Bulking Agent—A small percentage of Micro-Cel materially increases the bulk of dry powders—allows control of package density.

Pigment Extender—Micro-Cel's surface characteristics, fine particle size and large specific surface, combined with inertness, indicate its value as a pigment extender.

Suspension Agent—Micro-Cel's different combination of properties provides aid in suspension of heavier solids.

Flatting Agent—Micro-Cel's high absorption, fineness and particle shape indicate its value as a flatting agent.

Reinforcing Pigment—The combination of fine particle size, particle shape, and wetting characteristics suggests the value of Micro-Cel as a reinforcing pigment.

Some Proven Uses

Micro-Cel has already been proven as offering outstanding advantages as an absorbent-grinding aid for high liquid concentrate insecticide wettable powders, as an anti-caking agent in fertilizers, insecticide dusts, cleansers and detergents. Additional uses are being explored in Johns-Manville's Research Center.

Chemical Composition

Developed after years of research and experimentation by Johns-Manville, Micro-Cel is produced by the chemical combination of lime and diatomaceous silica under carefully controlled conditions. As a result, specific grades are available offering a wide range of physical properties.

RANGE OF PHYSICAL PROPERTIES

Color	white or off-white
*Absorption, % by weight	
Water	300-600
Oil	275-500
Bulk density, lb./cu. ft.	5-15
Ultimate particle size, micron	.02 to .07
pH	8.0-10.0
Moisture (free), wt., %	5-8
Refractive index	1.52-1.55
Available surface area, sq.m./gm.	95-175

*Will absorb 1 to 2½ times its weight in liquid and remain a free-flowing powder.

Samples Now Available

Micro-Cel is now available for laboratory and production evaluation. Write to Johns-Manville for further data on your specific problems. An engineer from J-M's Celite division will be glad to work with you in adapting Micro-Cel to your own particular requirements. Mail coupon today.

Johns-Manville, Box 60, New York 16, N. Y. CEP 12
In Canada: Port Credit, Ontario

☐ Please send additional data and samples of Micro-Cel. I am interested in formulating the following products:

_____

☐ Please have local representative contact me

Name _____

Position _____

Company _____

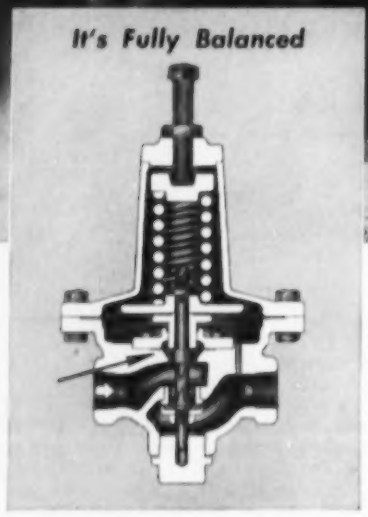
Address _____

City _____ Zone ____ State _____

-CEL **SYNTHETIC CALCIUM SILICATE**

A PRODUCT OF THE CELITE DIVISION

Here is the new LESLIE "HI-FLO" Water Reducing Valve with 50% more capacity



Unique construction of "Hi-Flo" Reducing Valve. Note the small lower diaphragm that provides fully balanced, floating action.

HERE IS THE ALL NEW Leslie Reducing Valve with *capacity-regulation* features that have never been offered before. Here is a regulator with 50 - 100% greater capacity by actual test.*

Here's the unbeatable combination of design features:

"HI-FLO" — Large bowl construction; long stroke diaphragm gives full flow of water and other non-corrosive liquids.

FULLY BALANCED — The main valve, fully balanced by lower diaphragm, virtually floats to provide smooth, friction-free, throttling action.

DROP-TIGHT SHUTOFF — Resilient seating disc provides tight closure under all conditions.

TROUBLE-FREE DESIGN — Chatter and hammer eliminated; no piston cups or seals to clog or change. Corrosion resistant trim with renewable interchangeable fit.

Ask your Leslie Engineer to show you how the exclusive Leslie "Hi-Flo" valve can be used to your advantage in water reducing stations, fuel oil pressure control, process lines, etc. He's in your classified directory under "Valves" or "Regulators".

Write today for Bulletin 553 for graphic performance comparison and complete capacity data.

TRADE LESLIE MARK

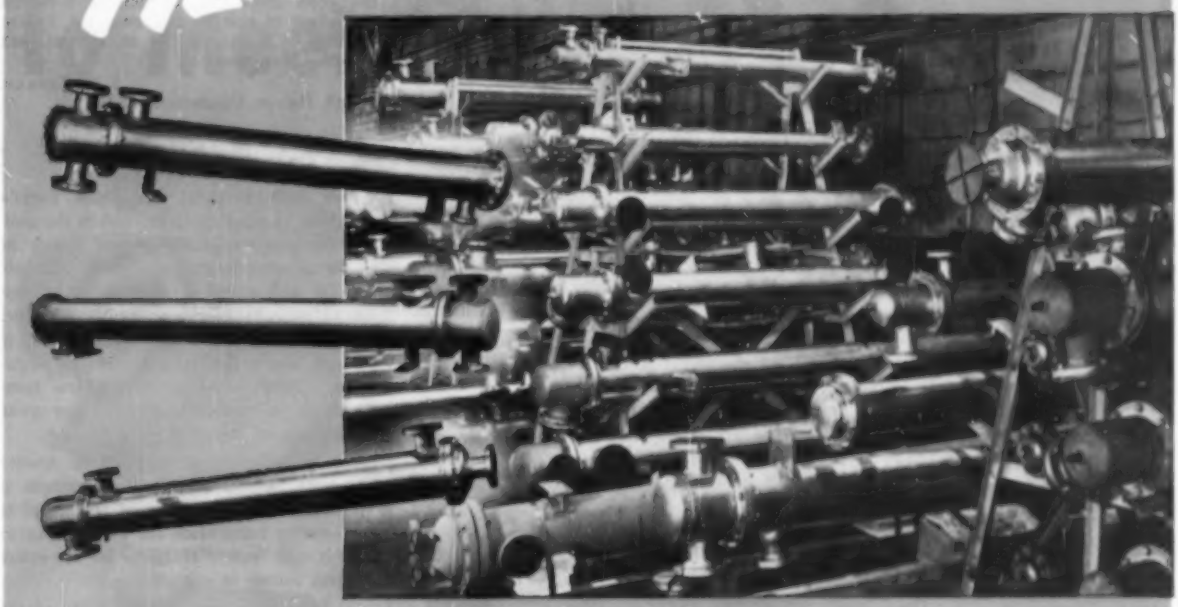
REGULATORS AND CONTROLLERS

LESLIE CO., 241 GRANT AVENUE, LYNDHURST, NEW JERSEY

CONTROLLED QUALITY MEANS QUALITY CONTROLS

Struthers Wells

Standard HEAT EXCHANGERS



Struthers Wells now offers a line of Standard heat exchangers—in sizes from 20 to 400 square feet of surface—including fixed tube sheet, floating head and U-tube units. Condensers, coolers, heaters and reboilers can be supplied in single and multipass tube arrangements.

Standard heat exchanger construction includes materials of carbon steel, non-ferrous alloy, and stainless alloys Type 304 and Type 316. Equipment meets highest construction standards, including ASME Code and TEMA Class A.

Typical units are illustrated above, including a partial view of those in stock, ready for immediate shipment. Standardization of design and quantity manufacture enables us to offer this equipment at very reasonable cost.

STRUTHERS WELLS PRODUCTS

PROCESSING EQUIPMENT DIVISION

Crystallizers . . . Direct Fired Heaters . . . Evaporators . . . Heat Exchangers . . . Mixing and Blending Units . . . Quick Opening Doors . . . Special Carbon and Alloy Processing Vessels . . . Synthesis Converters

BOILER DIVISION

BOILERS for Power and Heat . . . High and Low Pressure . . . Water Tube . . . Fire Tube . . . Package Units

FORGE DIVISION

Crankshafts . . . Pressure Vessels . . . Hydraulic Cylinders . . . Shafting . . . Straightening and Back-up Rolls

MACHINERY DIVISION

MACHINERY for Sheet and Structural Metal Forming . . . Tangent Benders . . . Folding Machines . . . Roller Table and Tumble Die Bending Machines . . . Press Brakes . . . Punching and Notching Machines . . . Forming Dies

Any Size Available for Quick Delivery!

STRUTHERS WELLS *Corporation*

Struthers Wells

WARREN, PA.

Plants at Warren, Pa. and Titusville, Pa.

Offices in Principal Cities

STAYS TOUGH
AT SUB-ZERO TEMPERATURES

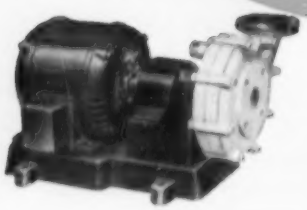
ACE PARIAN . . , odorless, tasteless, rigid polyethylene. Best chemical resistance of any plastic at room temp. except to acetic acid. Excellent impact strength at sub-zero temp. Rigid pipe ½" to 2". *Bul. 351.*

LIFE-TIME
ACID STORAGE TANKS
Rubber-lined by ACE
2-layer system

Economical, universal protection against all alkalis, metallic salts, practically all inorganic acids, hydrochloric acid any strength, sulphuric to 50%, nitric to 20%, phosphoric to 75%. Good to 160 deg. F. . . . sometimes higher. Soft rubber interlayer aids shock resistance.

Now eleven ACE Materials to STOP CORROSION

Eleven job-proved rubber and plastic materials now available in ACE piping, valves, pumps and tanks. Tough Ace-lite rubber-plastic blend . . . Saran . . . heat-resistant Tempron . . . Rivicior PVC . . . many others. Write for comparative properties Bulletin CE-50 . . . or call your American Hard Rubber Company distributor.



ACE "WAM" . . . THE FINEST
Non-metallic Acid Pump

On job after job, this 80-gpm. centrifugal pump has earned highest praise. Hard rubber casing and impeller, Hastelloy C shaft. Handles nearly all corrosives. Mechanically simple, trouble-free. *Bulletin CE-55.* Larger ACE pumps available.

NEED SPECIAL FITTINGS,
COVERS, TANKS, PARTS?

If you want life-time corrosion protection for special parts needed in quantity . . . we may save for you by molding them of ACE hard rubber or plastics to your most exacting requirements. Our facilities among world's largest. Ask for recommendations.

ACE processing equipment of rubber and plastics

AMERICAN HARD RUBBER COMPANY
93 WORTH STREET • NEW YORK 13, N. Y.

LETTERS TO THE EDITOR

(Continued from page 16)

lege at Memphis, University of Alabama, and the University of Mississippi.

FRANK A. ANDERSON

University, Mississippi

"Professional Standards"

Your November [1955] issue published a very timely and important message in the "Professional Standards" statement. I had the good fortune to participate in some discussion of this report when the Public Relations Committee met at Detroit last month. [November].

J. E. TROYAN

North Haven, Connecticut

On the Future of Education . . .

Few can disagree with Dean Elgin's summary of what has happened in the past and his analysis of the present trends in chemical engineering education. ("Engineering and chemical engineering of the future," J. J. Elgin, *C.E.P.*, December, 1955). As someone has said, "There is nothing like a few facts to stop an argument." However, I do have a few comments on his predictions of what may occur in the distant future.

As an advocate of *engineering science* for over twenty years I must concede it will become the backbone of the chemical engineering curriculum but I cannot agree that it may become the basis for the entire subject matter in engineering.

It is of course the responsibility of the colleges and universities to furnish us with people well-trained in the fundamentals and with some idea of the atmosphere and problems of industry together with the desire and aptitude to solve these problems. But will industry ever be able to do a good job in providing students with a *general* education, in the sense of actually teaching chemical engineering practice? I think not. Industry can and should give financial support. I would, however, much prefer to see people well qualified as educators in our colleges assume this responsibility.

On the subject of numbers of trained men, we should all agree that industry can make good use of a *few* well-trained brilliant engineering scientists, but we need a *great many* young people well trained in the fundamentals of science and in the broader field of knowledge of how to communicate with one another and "sell" their ideas to others.

In brief, what we need and are looking to the colleges to produce for us are young potential executives for the process industries.

DONALD B. KEYES

New York, N. Y.

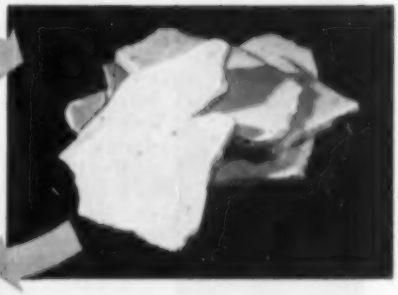
(Noted and Quoted on page 28)

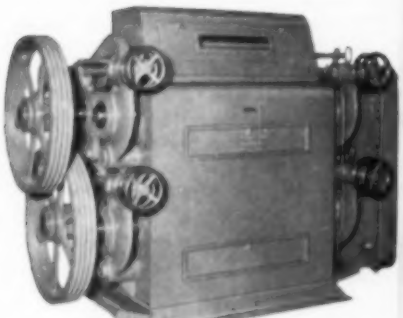
ALLIS-CHALMERS
PROCESS SYSTEM

Converts Fine Particles Into

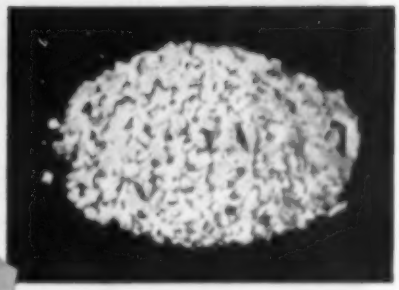
Granular Product To Meet Consumer Demand

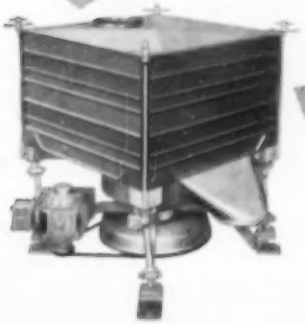
Compacting Mill





Roller Mill





Circle Sifter

1 Recovery operation starts with unacceptable minus 30 mesh chemical salt — fines created in original process.

2 An Allis-Chalmers heavy duty compacting mill is the principal component in the recovery system. The flakes or slabs illustrated are the result of mechanical densification in the compacting mill. An Allis-Chalmers two-pair high corrugated roller mill is used to granulate flakes. Final separation is made in the *Circle* sifter — an Allis-Chalmers gyratory screen. An 80% to 90% recovery of salable product is effected.

3 The resulting granules (100% minus 3 mesh and 100% on 10 mesh) equal or surpass natural product in every respect. Reconstituted product differs little from parent product in abrasion tests. Other tests have proved the compacted granule superior in controlled solubility. Granulated product is more uniform in particle size, flows more freely and has better "eye-appeal."

A-4743

For complete information, see your A-C representative or write Allis-Chalmers, Milwaukee 1, Wisconsin, for Bulletin 25C6177J.

Circle is an Allis-Chalmers trademark.

ALLIS-CHALMERS

BELT CONVEYORS

VIBRATING CONVEYORS

REDLER CONVEYOR-ELEVATOR

ZIPPER CONVEYOR-ELEVATORS

BUCKET ELEVATORS

PAN CONVEYORS

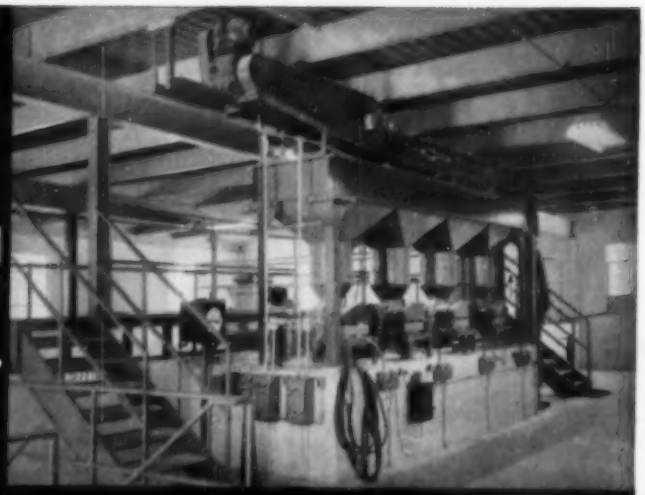
VIBRATING SCREENS

BIN GATES—ALL KINDS

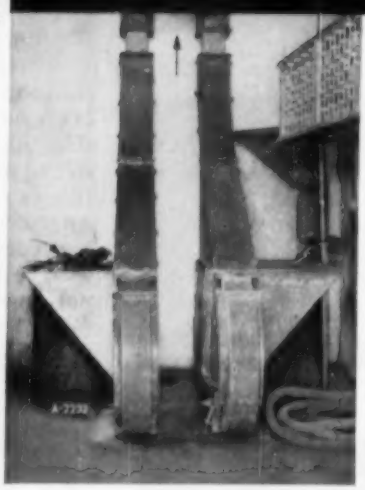
CIRCULAR BIN DISCHARGERS

SEALMASTER BALL BEARING UNITS

LIME and SODA ASH ON THE DOUBLE!



S-A REDLER CONVEYOR ELEVATOR SYSTEM provides water treatment for Village of Clyde

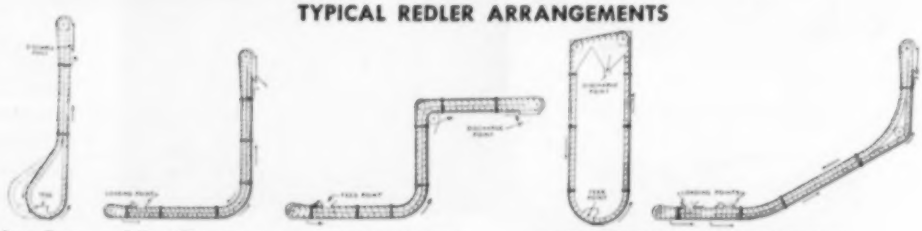


The municipal water treatment plant at the Village of Clyde, Ohio, contains twin S-A Redler loop boot vertical and horizontal conveyors for delivery of hydrated lime and soda ash.

Inherently economical, this type Redler requires no boot pit since loading point is only slightly above floor level. Furthermore, no special feeding apparatus is needed. Bulk materials which have a tendency to aerate are fed to the return side of conveyor loop. A seal in the load is thereby created, permitting material to move smoothly and in a solid column to point of discharge. Minimum space requirements for this S-A system is an important factor in small plant installation.

As was true at Clyde, simple adaptations of standard S-A conveyor products very often provide extremely low cost and efficient bulk material handling. In fact, Stephens-Adamson's wide product range and versatility can often provide a conveying system that is virtually "in stock."

TYPICAL REDLER ARRANGEMENTS



Loop Boot Elevators | L-Type Elevator-Conveyor | Z-Type Elevator-Conveyor | Vertical Closed Circuit Elevator | Special Elevator-Conveyor

FREE BULLETINS AVAILABLE ON ALL THESE PRODUCTS

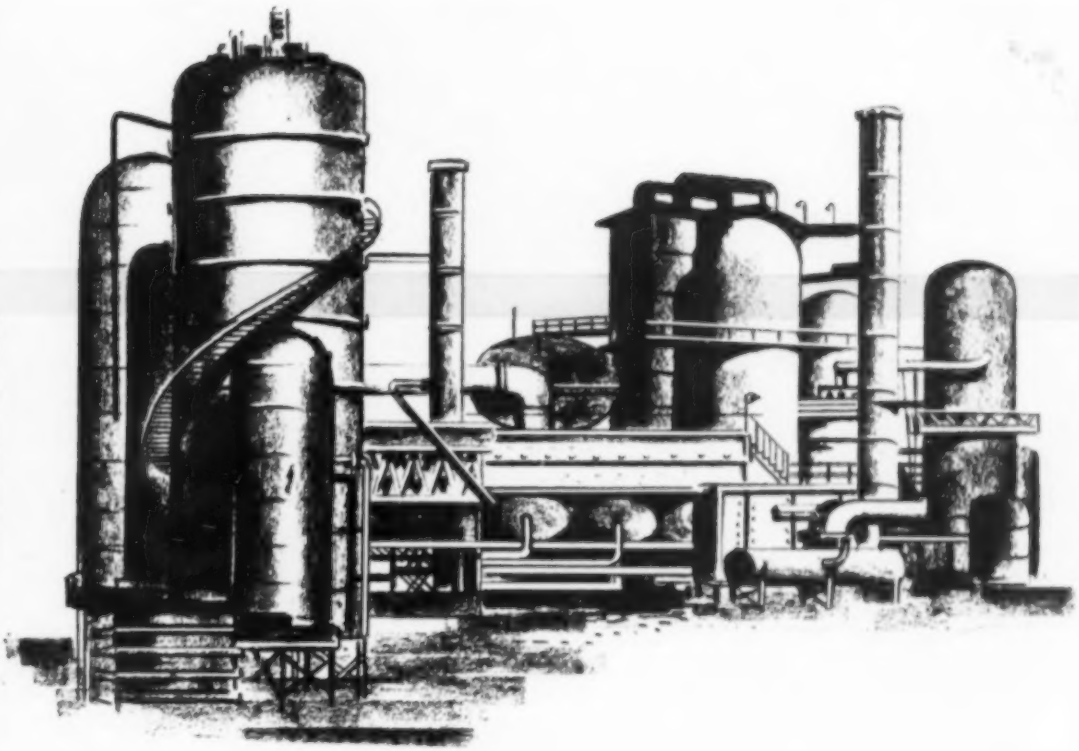
STEPHENS-ADAMSON MFG. CO.

57 Ridgeway Ave., Aurora, Ill.—Los Angeles, Calif.—Belleville, Ontario.

ENGINEERING DIVISION
Designers and manufacturers of all types of bulk materials conveying systems.

STANDARD PRODUCTS DIVISION
A complete line of conveyor accessories—centrifugal loaders—car pullers—bin level controls, etc.

SEALMASTER DIVISION
A full line of industrial ball bearing units available in both standard and special housings.

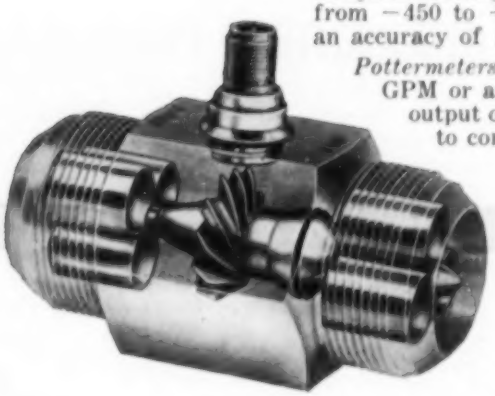


FOR VITAL FLOW CONTROL

WHETHER you're developing a new process or modernizing an old one—investigate the unique characteristics of the bearingless *Pottermeter.*

This electronic flowmeter—easily installed in any type of piping to operate at any angle, at any pressure and at temperatures from −450 to +1200°F, measures flow of any liquid with an accuracy of ±½ of 1%.

Pottermeters are available to measure flows as low as 0.07 GPM or as high as 3,000 GPM. The inherently linear output of the *Pottermeter* makes it ideal for systems to control either flow rate or total flow.



Find out how the bearingless "floating rotor" used in the *Pottermeter* can give you more precise flow measurement, longer trouble-free service life, and more accurate flow control.

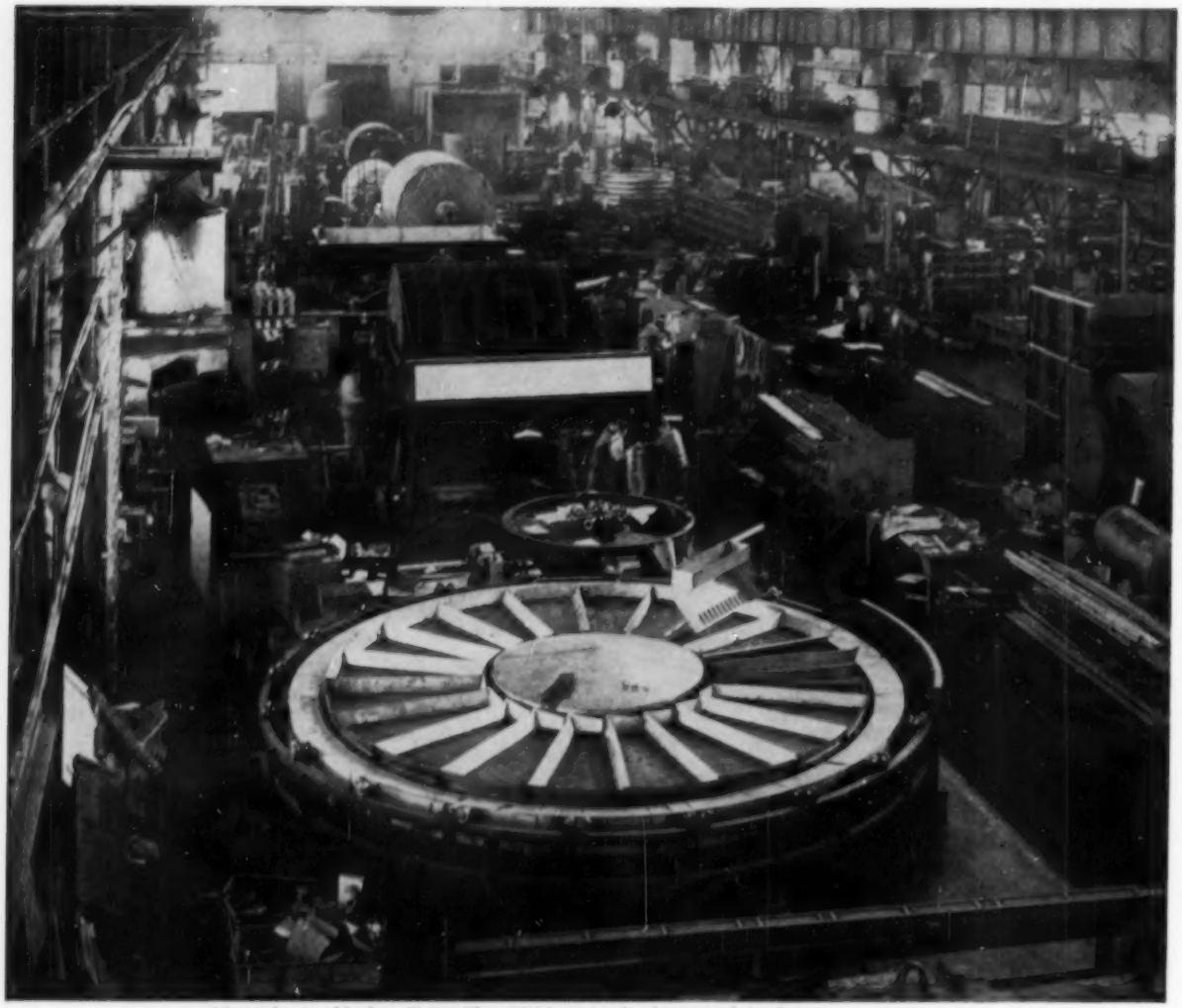
Write for Bulletin PS-1

Potter

POTTER AERONAUTICAL COMPANY

Route 22 • Union, New Jersey • Phone MUrdock 6-3010

Makers of "Potter Engineered" products



View of assembly bay Eimco Filter Division. In the foreground is shown 120 sq. ft. pan filter, all stainless steel construction for phosphoric acid.

SPECIFY EIMCO FILTERS FOR GUARANTEED PERFOMANCE

Eimco filters are built to meet the exacting requirements of process engineers all over the world.

The wide range in types of filters available at EIMCO include both vacuum and pressure designs in: Drums, Discs, Agidiscs, Top Feed, Dewaterers and Dryers, Pans, Tubular elements and Plate and frames. Each of these designs is available with numerous attachments for cake dewatering and cake removal. Materials of construction are selected with regard to the material to be filtered.

Every filter job receives individual attention at Eimco. The Eimco filter delivered in your plant provides you with the finest filtration equipment you can buy at any price and with a machine guaranteed to perform on your product.

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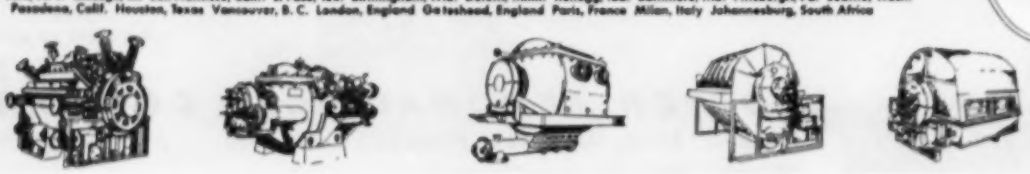

B-178

Moly catalysts are versatile

Because of its versatility, molybdenum is one of the most widely used catalytic elements. As a transition element, it has the incomplete inner shell of electrons needed for catalytic activity. Ease of transition from one to another of its six valence states allows it to function readily as an electron acceptor or donor. It forms a variety of compounds in all valence states, most of them resistant to common catalytic poisons. Commercially, molybdenum catalysts are used in seven types of reactions: oxidation, hydrogenation, dehydrogenation, isomerization, cyclization, chlorination and condensation. Promising results have been obtained in dehydration, polymerization and alkylation. For complete data write Department 25, Climax Molybdenum Company, 500 Fifth Ave., New York 36, N. Y. for our bulletin, "Molybdenum Catalysts for Industrial Applications."

CLIMAX MOLYBDENUM

Courtesy of Hoffritz for Cutlery, 331 Madison Avenue, New York

Only CONSECO Offers Such SERVICE

CONSECO SERVICE is two-fold. **On one hand, our engineers will design, redesign, build, erect, and install practically everything in a modern power or chemical processing plant except the building, electrical equipment, and turbo-generator. On the other hand, we will dispatch an expert crew to your plant for retubing, rebuilding, and maintenance of any type of tubular equipment, or metallizing . . . ANY HOUR, DAY or NIGHT, SUNDAYS and HOLIDAYS. Conseco's coordinated manufacturing and maintenance services meet every need in the Power and Processing fields.**

CONDENSER SERVICE & ENGINEERING CO., INC. CONSECO

Designers and Builders of Equipment for Power, Refining, Chemical and Marine Industries

64 Bloomfield Street
HOBOKEN, N. J.

Equipment Designed and Built by CONSECO

Conseco and its subsidiaries design, build, and install power and processing equipment and accessories, some of which are listed here. Purchasers of Conseco equipment benefit from our maintenance division's quarter century experience in rebuilding, modernizing, and maintaining our own as well as competitors' equipment. This coordination assures easy accessibility for maintenance and low operating cost. Send for bulletins covering equipment in which you are interested.

Heat Exchangers
Condensers
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Steam Generators
Pressure Vessels
Centrifuges
Filters and Strainers
Pumps, Instruments, Specialties

NOTED AND QUOTED

Goobers and Geraniums

Once it was silver and gold that lured prospectors to these wide open spaces [Virginia City, Nevada]. Today, of course, it's uranium. One old-timer was mighty mystified by the new invaders. "Dunno what this excitement is all about," he confided to a reporter from the *Louisville Courier-Journal*. "Fust thing I knew was when some feller come on the place with a contraption called a Goober counter and seemed hell-bent on huntin' for geraniums."

Bennett Cerf
Trade Winds, *Saturday Review*

Science and Art of Engineering

The art aspect of engineering seems to have fallen into ill repute; it has become associated in the minds of many with rule-of-thumb methods, with handbook engineering, and with the use of empirical methods when rational approaches might better be employed. Because certain phases of the art have been recognized as undesirable and subprofessional, there has been a definite tendency to conclude that all of the art of engineering is undesirable and subprofessional. Nothing, of course, could be farther from the truth. While the routine phases of either the art or the science of engineering are frequently subprofessional in character, the judgment and imagination involved in either one—and more likely to be demanded by the art—may well represent the highest form of professional expression. The betterment of our environment depends on what is done rather than on scientific complexity. Creativeness should be measured by its potential influence on human welfare rather than by emphasis on either science or art.

Herein lies the paradox of professional education in engineering: that emphasis on the basic sciences and mathematics, though essential, tends to encourage systematized thinking and so to inhibit the development of judgment and imagination—qualities essential to the highest type of professionalism. If, in the name of professionalism, engineering education veers too far in the direction of science, that part of the art that exemplifies truly professional practice can be crowded out, thereby leading only to a high type of vocationalism—to scientific vocationalism. As soon as any

(Continued on page 32)

Here's how to solve your VAPOR PHASE ADSORPTION PROBLEMS with Pittsburgh Activated Carbon

TYPICAL BPL APPLICATIONS

Solvent Recovery

Provides proven performance and distinct cost savings in solvent recovery systems.

Gas Purification

Ideal for purification of many chemical and petrochemical gases. Example: Removal of sulfur impurities.

Catalysis

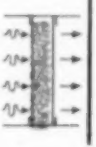
Excellent catalyst and catalyst support in production of vinyl monomers and similar applications.

Hydrocarbon Separation

Ideal for separating higher molecular weight hydrocarbons from gas streams.

Air Purification

Used in industrial air conditioning and purification of air required for aerobic fermentation.



Odor Removal

Used to reduce harmful and odoriferous components in waste gases to minimal concentrations.

PITTSBURGH Type BPL Granular Activated Carbon is specifically designed to solve vapor phase adsorption problems more efficiently and at appreciably lower cost than any other similar material. Made from a selected grade of bituminous coal under rigidly controlled conditions, *Pittsburgh* BPL offers you these important advantages:

1. Controlled pore size.
2. High surface area.
3. High density—high volume activity.
4. Chemical inertness.
5. High thermal stability
6. Range of mesh sizes.

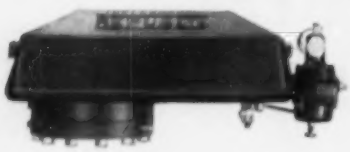
And, due to its unique raw material base, *Pittsburgh* BPL Granular Activated Carbon costs far *less* than other carbons of equivalent performance characteristics.

Write today for samples and full information on prices and specifications of *Pittsburgh* BPL Activated Carbon.

COAL CHEMICALS • PROTECTIVE COATINGS • PLASTICIZERS • ACTIVATED CARBON • COKE • CEMENT • PIG IRON

Here's Force-Balance* Accuracy and Ruggedness in a Complete Line of Pneumatic Transmitters . . .

FLOW, LEVEL, or DENSITY TRANSMITTER—Differential Type

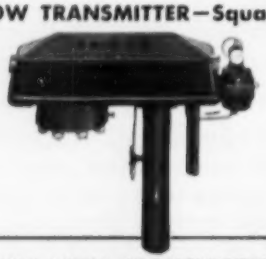


Available with differential ranges as low as 0—0.6" H_2O (ranges this low are exclusive with the Republic Transmitter) and as high as 0—750 psi. Range may be suppressed up to 80% of full scale for density or level measurements.

PRESSURE and ABSOLUTE PRESSURE TRANSMITTER

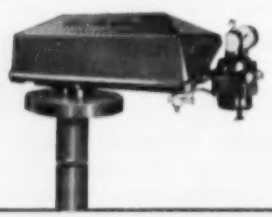
Pressure ranges from 0—1" H_2O to 0—2000 psi. May be easily adapted for absolute pressure ranges from 0—25 mm Hg to 0—100 psia.

FLOW TRANSMITTER—Square Root Extracting Type



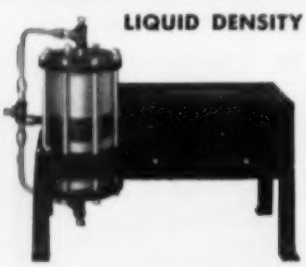
Automatically extracts square root function from flow measurements, permitting use of uniformly graduated charts and linear control devices. Available in all standard differential ranges.

LIQUID LEVEL TRANSMITTER—Bouyancy Type



Ranges to suit most applications. Can be used to measure level in closed tanks under pressure. Can also measure liquid-to-liquid interface.

LIQUID DENSITY TRANSMITTER—Bouyancy Type



Makes continuous density measurement of flowing liquids at line pressures to 300 psi. Fast response.

PNEUMATIC or PNEUMATIC-ELECTRIC TRANSMISSION

Special electrical meter body available for use with most Republic Pneumatic Transmitters. Permits locating pneumatic transmitter at metering point to cut piping costs and keep dangerous fluids out of control rooms.

for Measuring FLOW—PRESSURE—LEVEL—DENSITY

Republic Pneumatic Transmitters are as simple in operating principle as a laboratory weigh scale—and just as accurate! The only real difference is that forces instead of weights are balanced for a measurement.

This force-balance principle both permits and requires the use of strong, durable construction. That's why Republic Transmitters can be ruggedly built for low maintenance without sacrificing accuracy and sensitivity. Standard models are *guaranteed accurate* to ½% of full scale.

Range Flexibility — Changing ranges is merely a matter of shifting leverages in Republic Transmitters. Ranges may be changed as much as 2-1 on standard models, as much as 10-1 on double weighbeam models *with no change of parts.* Suppressed, reversed and compounded ranges are also readily available.

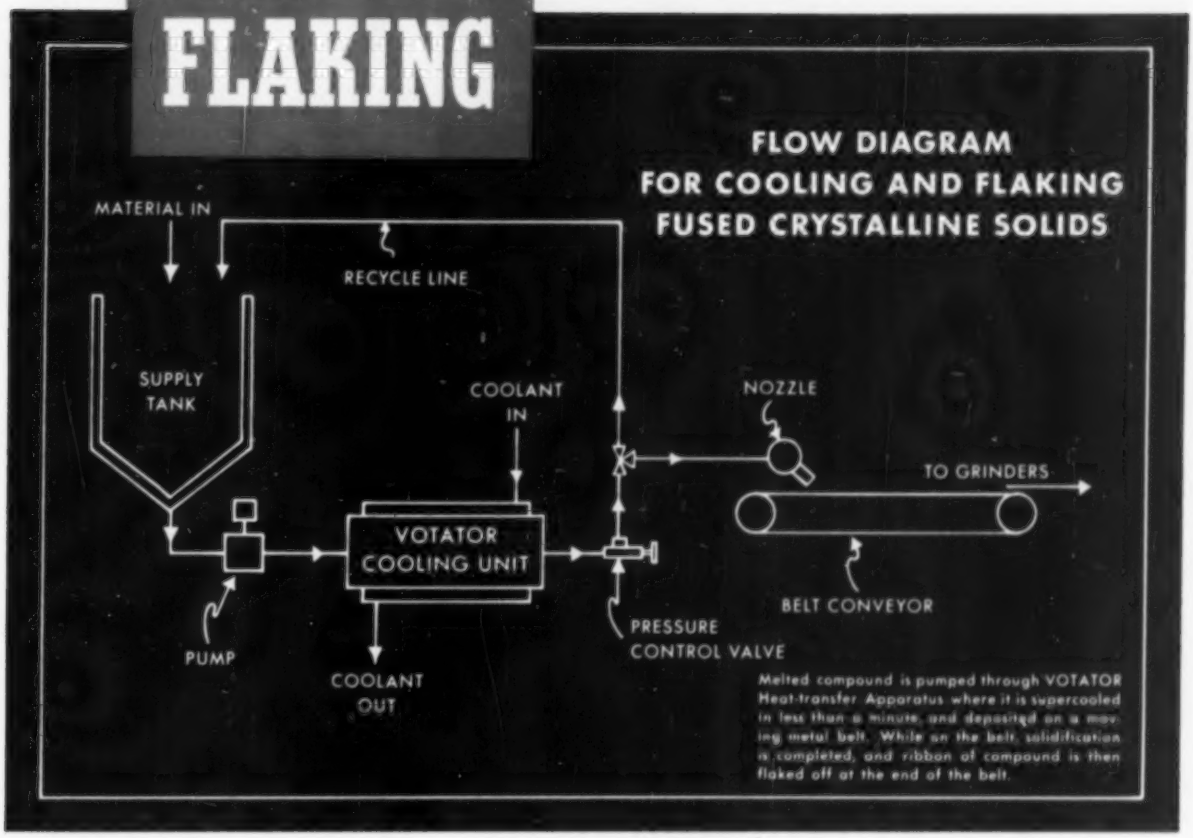
Corrosion Protection — Since process fluids are isolated to a small measuring chamber, special materials may be used for corrosion resistance. Minimum movement of fluid in chamber cuts maintenance when transmitter is used with dirty or viscous liquids.

These are but a few of the many features found in Republic force-balance Transmitters. Write for a free copy of Data Booklet with all of the details and complete description of various types.

*In a force-balance pneumatic transmitter, a force produced by the process variable is balanced against a pneumatic pressure. The amount of air pressure required to produce a balance is proportional to the process variable and may be conducted to remote reading instruments or used as the measuring impulse for an automatic controller.

REPUBLIC FLOW METERS CO. • 2240 Diversey Pkwy., Chicago 47, Illinois

FLAKING


FLOW DIAGRAM
FOR COOLING AND FLAKING
FUSED CRYSTALLINE SOLIDS
MATERIAL IN
RECYCLE LINE
SUPPLY TANK
COOLANT IN
NOZZLE
TO GRINDERS
VOTATOR COOLING UNIT
BELT CONVEYOR
PUMP
PRESSURE CONTROL VALVE
COOLANT OUT
Melted compound is pumped through VOTATOR Heat-transfer Apparatus where it is supercooled in less than a minute, and deposited on a moving metal belt. While on the belt, solidification is completed, and ribbon of compound is then flaked off at the end of the belt.

Controlled supercooling with *Votator*® Heat-transfer Apparatus produces better crystal structure

A NEW PROCESS for flaking fused crystalline solids employs VOTATOR* Heat-transfer Apparatus for continuous supercooling under precise mechanical control. Applications include DDT and similar compounds (methoxychlor), which on cooling from the melted state supercool to a marked degree. The VOTATOR Heat-transfer Apparatus supercools them to a slush or semi-solid.

This automatic continuous process permits very accurate control of crystallization temperature and other solidifying conditions. As a result, the flaking material has a uniformly fine crystal structure with excellent grinding properties. Without such continuous, positive control, crystallization can be retarded, or the flakes can become waxy and difficult to grind properly. The system is completely enclosed, eliminating danger to personnel from toxic compounds. Automatic operation reduces labor requirements and permits efficient operation at various production rates.

VOTATOR Heat-transfer Apparatus can improve efficiency and product quality in many processes such as listed. Write for copy of Heat Transfer Data Book.

*VOTATOR Trade-Mark Reg. U. S. Pat. Off.

GIRDLER DESIGNS processes and plants
GIRDLER BUILDS processing plants
GIRDLER MANUFACTURES processing apparatus

VOTATOR DIVISION:
Complete Edible Oil Plants;
Continuous Processing Apparatus for . . .

Cooking	Sulfation	Lubrication Grease
Cooling	Nitration	Paper Coating
Controlling Heat of Reaction	Crystallization	Paraffin Wax
	Polymerization	Synthetic Wax
Emulsification	Textile Size	Resins
Sulfonation	Shaving Cream	And other Products

The GIRDLER Company

A DIVISION OF NATIONAL CYLINDER GAS COMPANY
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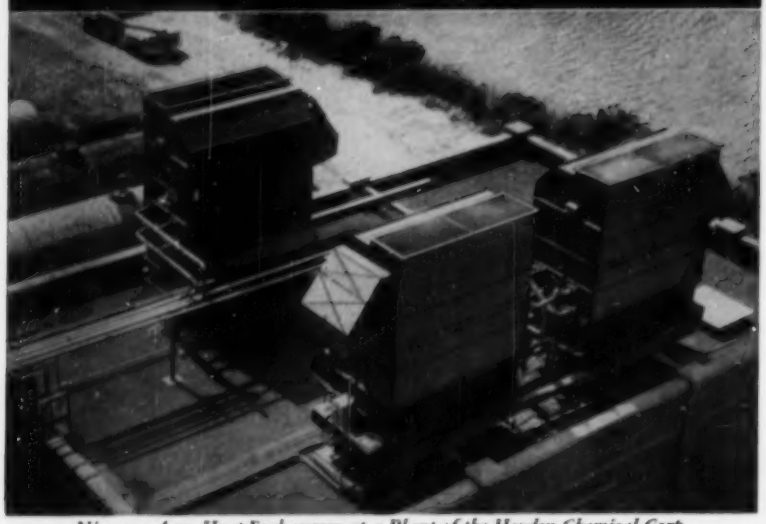
IMPROVED CONDENSING and Cooling of Reflux



Niagara Aero Heat Exchangers at a Plant of the Heyden Chemical Corp.

Get Better Control of Distillation Product

● Liquid or vapor temperatures are always held constant by the Niagara "Balanced Wet Bulb" control method of evaporatively cooling or condensing, which automatically varies the cooling effect proportionately to the load. The distillation product is therefore uniform throughout all changes in climatic conditions the year around; it is the same in the heat of summer as in the freezing cold of winter. Continuous maximum production is thus insured.

Non-condensibles are effectively separated at the condensate outlet, with notable sub-cooling after separation for greater vacuum pump efficiency.

NIAGARA AERO HEAT EXCHANGERS give sustained full capacity in cooling and condensing with no dependence on cooling water . . . eliminating problems of water supply, availability, temperature, or quality.

For full information write for Bulletin 120

NIAGARA BLOWER COMPANY

Over 35 Years of Service in Industrial Air Engineering

Dept. E.P., 405 Lexington Ave. New York 17, N. Y.

District Engineers in Principal Cities of U. S. and Canada

NOTED AND QUOTED

(Continued from page 28)

area of knowledge becomes systematized it becomes largely subprofessional in character. . . . If a thing is systematized, it can be mechanized; or, if mechanization should be found uneconomical, it can be highly organized for inexpensive and subprofessional operation.

Let us not, then, in our effort to raise the professional character of engineering education, mistake scientific content for professionalism, nor mathematical complexity for engineering achievement. Let us rather recognize that art as well as science is intrinsic in the profession of engineering, and strive for a balance between the two. Let us not pit the one against the other, but draw on the fullness that each can offer for our educational program.

This plea for a recognition of all that the art of engineering can offer to engineering education is in no sense a plea to weaken the role of science. Indeed it is the reverse of this, for only when science and art complement each other can science become truly effective in engineering. Then—and only then—can science support a structure that extends far . . . into the greater realm of conflicting realities which is the true domain of professional engineering.

John B. Wilbur
in Civil Engineering

Men of the Hour

Total research outlays are now running at close to a $5 billion annual rate, not including capital outlays for research equipment. About 70 percent of this enormous research effort is being conducted by private business, which is now employing upwards of 100,000 research engineers and scientists, supported by a still larger number of laboratory, clerical, and administrative personnel.

Over 700 engineers and scientists are at work on research problems in the textile industry; over 1,200 in the stone, clay, and glass industry; over 1,700 in primary metals; over 2,000 in the nonelectrical machinery industry; more than 13,000 in the various branches of the chemicals industry. On average, American industry is now employing one research scientist for every 140 factory workers; one research employee (including scientist and supporting workers) for every 55 factory workers.

Martin R. Gainsbrugh
in Stanford Research Institute Bulletin

(Marginal Notes on page 36)

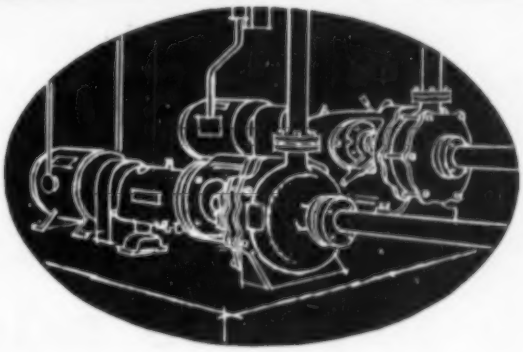
DURCOPUMPS WERE SELECTED

FOR URANIUM PROCESSING AT

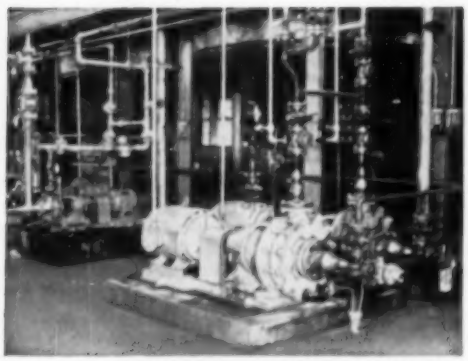
ELDORADO MINING & REFINING, LTD.,

PORT HOPE, ONTARIO, REFINERY.

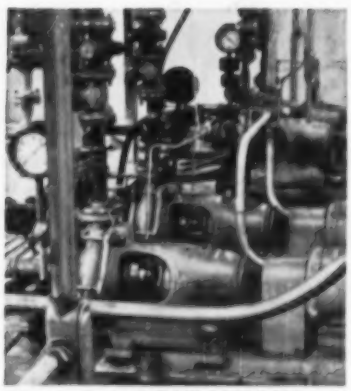
Series H Durcopump



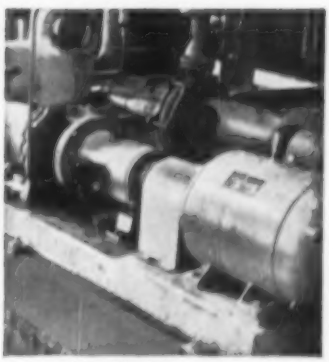
Series R Durcopump



Series R DURCOPUMPS and the DURCO Type F valves in the foreground handle a slurry containing acid insolubles, metal nitrates, and free nitric acid. Another Series R DURCOPUMP (background) handles nitric acid filtrate.



The two Series F DURCOPUMPS and the DURCO Type F valves in the foreground handle scrub liquor with up to 1% nitric acid. The DURCOPUMPS in the rear handle a raffinate slurry containing metal nitrates, acid insolubles, and free nitric acid.



Series H DURCOPUMP (front) handles a nitric and sulfuric acid slurry, specific gravity 1.8-2.0, with a high viscosity at 175° F. Series R DURCOPUMP in the rear is a filter feed pump handling a neutral slurry.

Eldorado Mining and Refining, Limited, a Crown Company, processes uranium to a Metal Grade Oxide.

DURCOPUMPS and DURCO valves were chosen to provide long service life with minimum maintenance. For complete details regarding this and other DURCO chemical service equipment, contact your nearest DURCO engineer or write

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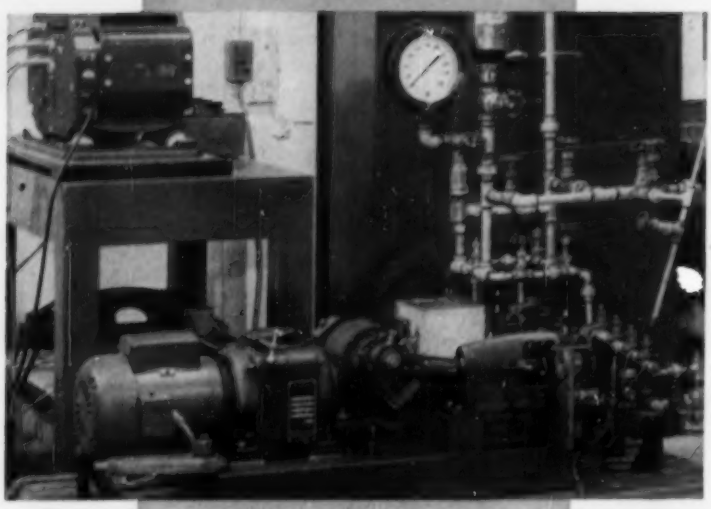
DURCO

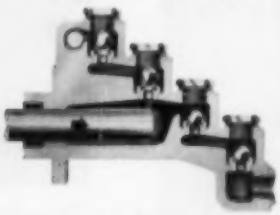
Branch Offices—Atlanta, Boston, Buffalo, Chicago, Cleveland, Detroit, Houston, Knoxville, Los Angeles, New York, Philadelphia, Pittsburgh • Represented in Canada by Shawinigan Chemicals, Limited



Standard motor-driven Controlled Volume Pump being tested for accuracy by independent research organization. *For details of test procedures and results, write for Technical Paper No. 55-1-1.*

Required accuracy for metering process additives

Exclusive Milton Roy
STEP-VALVE LIQUID END



Double ball checks, sloping passages and absence of air pockets assure highest possible volumetric efficiency. Should a solid particle lodge under one suction ball, for example, second suction ball will seat on discharge stroke, thereby preventing fluid from being pumped into suction piping.

THE INHERENT accuracy (within ± one percent) of Milton Roy Controlled Volume Pumps can solve your chemical metering problem. As flow controllers, these units simultaneously meter and pump process fluids. As ratio controllers, they maintain a fixed relationship between additives and process streams. As final control elements they contribute to accurate regulation of pH and other process variables.

There is a Milton Roy Controlled Volume Pump or chemical feed system for practically every chemical metering need. Capacities range from 3 milliliters per hour to 45 gallons per minute, with flexible adaptations for manual or automatic control of pump capacity. Pressures up to 50,000 psi.

Write for application data contained in the bulletins listed below. One of these will probably suggest the simple, economical solution to your chemical metering problem.

Bulletin 455 "Controlled Volume Pumps in Paper Making"

Bulletin 953 "Controlled Volume Pumps in Industrial Water Treating"

Bulletin 1253 "Controlled Volume Pumps in Process Instrumentation."

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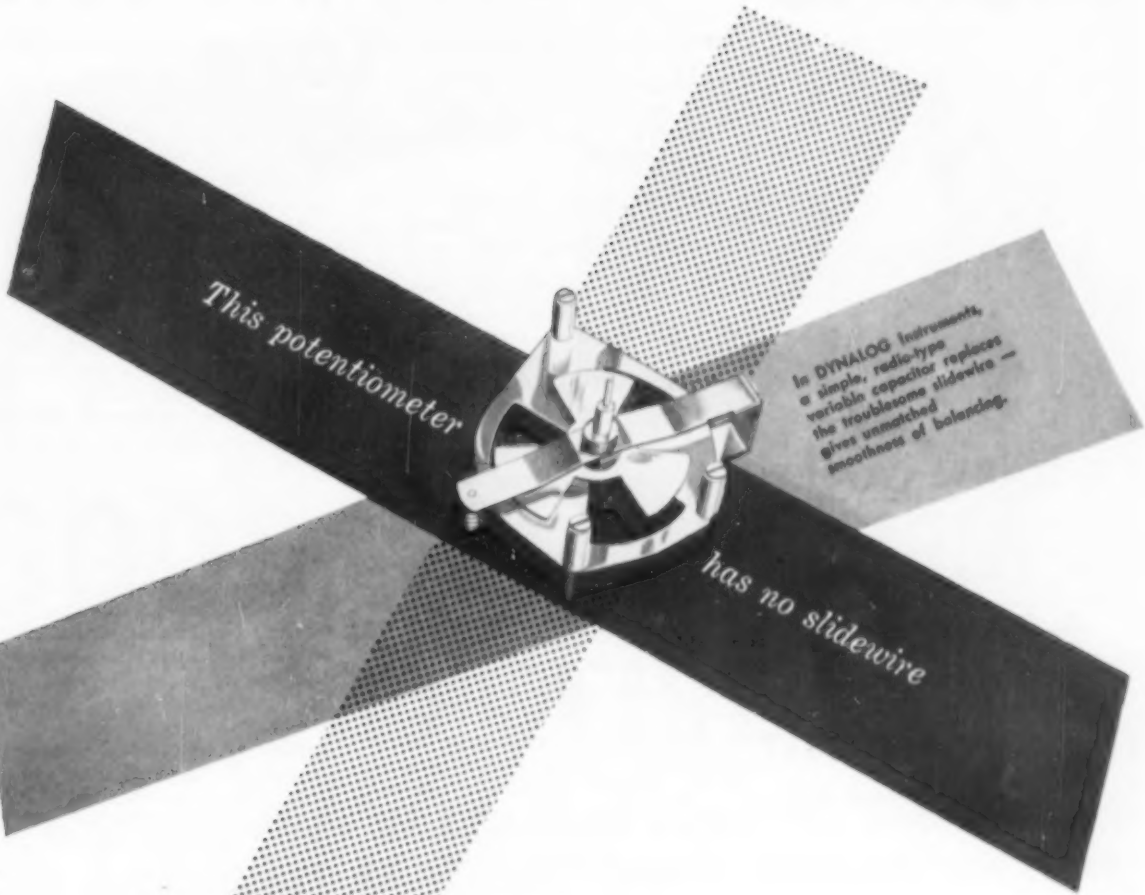
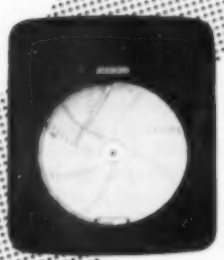
Engineering Representatives in the United States, Canada, Mexico, Europe, Asia, South America and Africa.

milton Roy
CHEMICAL FEED SYSTEMS


This potentiometer
has no slidewire
In DYNALOG Instruments, a simple, radio-type variable capacitor replaces the troublesome slidewire — gives unmatched smoothness of balancing.

STEPLESS CAPACITY-BALANCING
ELIMINATES STANDARDIZING!



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- no batteries
- no standardizing
- no gears, cables, etc.
- no high-speed reversing motor

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Dynalog* design eliminates slidewire maintenance and motor servicing too! A simple, variable capacitor and positive magnetic drive provide smooth, continuous balancing action . . . instant response without wear. There are no fast-moving parts . . . no gears, cables, or complicated mechanisms. Only five moving parts, including the recording pen!

Dynalog Instruments are available for use with resistance, voltage, capacity, or inductive type primary elements to measure and/or control any process variable. For complete details, write for Bulletin 427. The Foxboro Company, 932 Neponset Ave., Foxboro, Mass., U.S.A.

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MARGINAL NOTES

Mass-Transfer Operations. Robert E. Treybal. McGraw-Hill Book Company, Inc., New York (1955), 666 pages, $9.50.

Reviewed by E. L. Gaden, Jr., Department of Chemical Engineering, Columbia University, New York.

Professor Treybal's latest contribution to the chemical engineering bookshelf is a solid one. He has filled a gap, too long apparent, in the text and general reference books available to chemical engineers. Despite the close association of the mass-transfer—or diffusional—operations with the development of modern chemical engineering, this over-all province has not been adequately handled in a book. This situation is particularly noticeable in undergraduate instruction where existing works are, with few exceptions, too specialized or too old. Although individuals may find shortcomings from their particular points of view, Treybal's book has nevertheless answered the needs of the profession rather well for the moment.

The book is organized along conventional lines, offering first a discussion of the principles of diffusion and mass transfer, followed by treatments of gas-liquid, liquid-liquid, and solid-fluid operations in that order. A final, short section considers the contact of miscible phases, mainly dialysis and gaseous diffusion techniques.

The section on gas-liquid operations, comprising well over a third of the book, is novel in that general design features of the various equipment types employed are discussed first. Various contacting devices, towers, packing materials, and their essential performance characteristics in terms of capacities and pressure drops, are described first. After this, humidification, gas absorption, and distillation are treated individually.

In his preface the author comments on the ways in which a treatment of mass transfer,—or any subject for that matter—may be organized and offers his presentation on the basis of his own experience. It is with this very organizational scheme that this reviewer takes primary issue, recognizing full well that it is purely a matter of opinion. Rather than continuing an artificial fragmentation of the subject into topics like distillation and absorption, etc., only on early technological uses, a more integrated and generalized approach seems possible without any loss of essential information. In our tendency toward generalized approaches and emphasis on fundamentals, we often overlook the need for providing a certain fund of necessary technical knowledge to the student. Professor Treybal notes this point, quite rightly, but it is not a convincing argument for his plan.

An alternative approach, recently instituted here, is to develop basic subjects, like prediction and measurement of equilibrium conditions, stage calculations, diffusion and mass transfer rates, etc., and show how each is adapted to the solution of specific design problems in distillation, extraction, and others. This way the fundamental approach is emphasized without loss of particular information.

It should be added that this disagreement should offer no difficulty at all in using the book in courses taught by those following a different teaching tack. In fact there is probably a considerable gain if lectures and text approach the subject from different viewpoints.

Aside from this disagreement, two criticisms of some importance can be offered. First, the author makes no use of enthalpy-concentration charts for the solution of distillation problems. In view of the growing utility and popularity of the method, this omission seems unjustified. Of course the principle is developed quite fully under extraction, but its application first to distillation seems easier to explain and understand, at least in our experience. Second, the newer "penetration model" for explaining interphase transport should merit more than the footnote which it gets. It is true that separation process design methods have been pretty well limited to the transfer coefficient approach, but a page or two on the alternative seems a minimum requirement.

There are a few minor discrepancies in equations but they are insignificant and easily corrected. In reading over the book, one gets that impression of care and thoroughness so often lacking. The book is amazingly complete, yet certainly not overly large. In addition a considerable number of problems (without solutions to get less ambitious teachers busy) and a well-rounded set of references to the important literature are offered after each chapter.

In summary, this reviewer feels that the book is an excellent contribution to the literature of chemical engineering. Whereas it will be particularly attractive for teaching, the completeness and clarity of the book should make it a valuable reference for chemical engineers of all breeds.

(*More Marginal Notes on page* 44)

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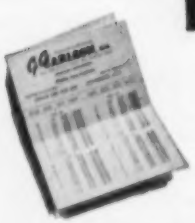

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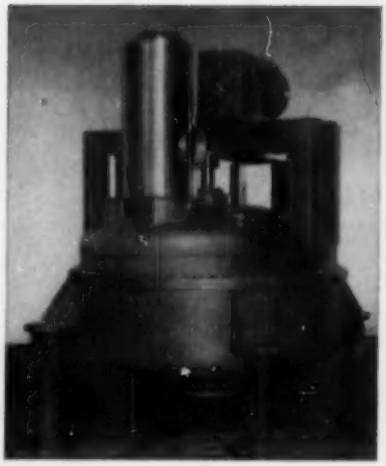

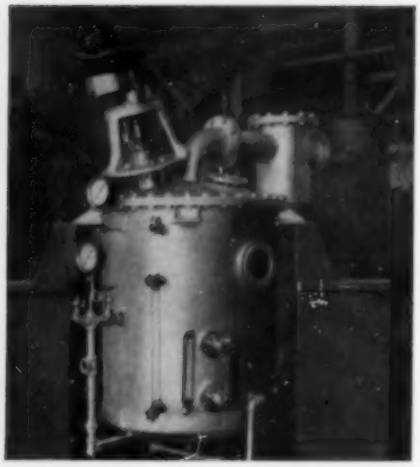

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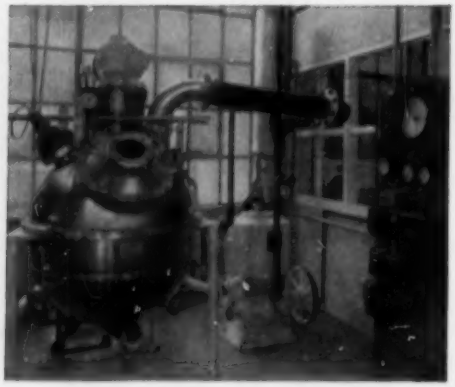

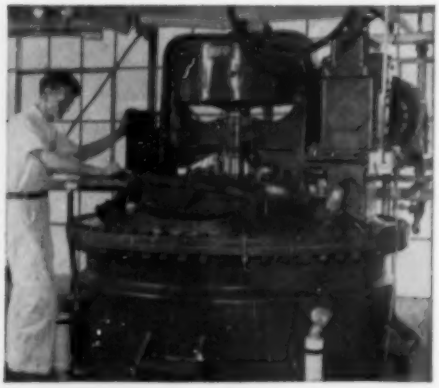

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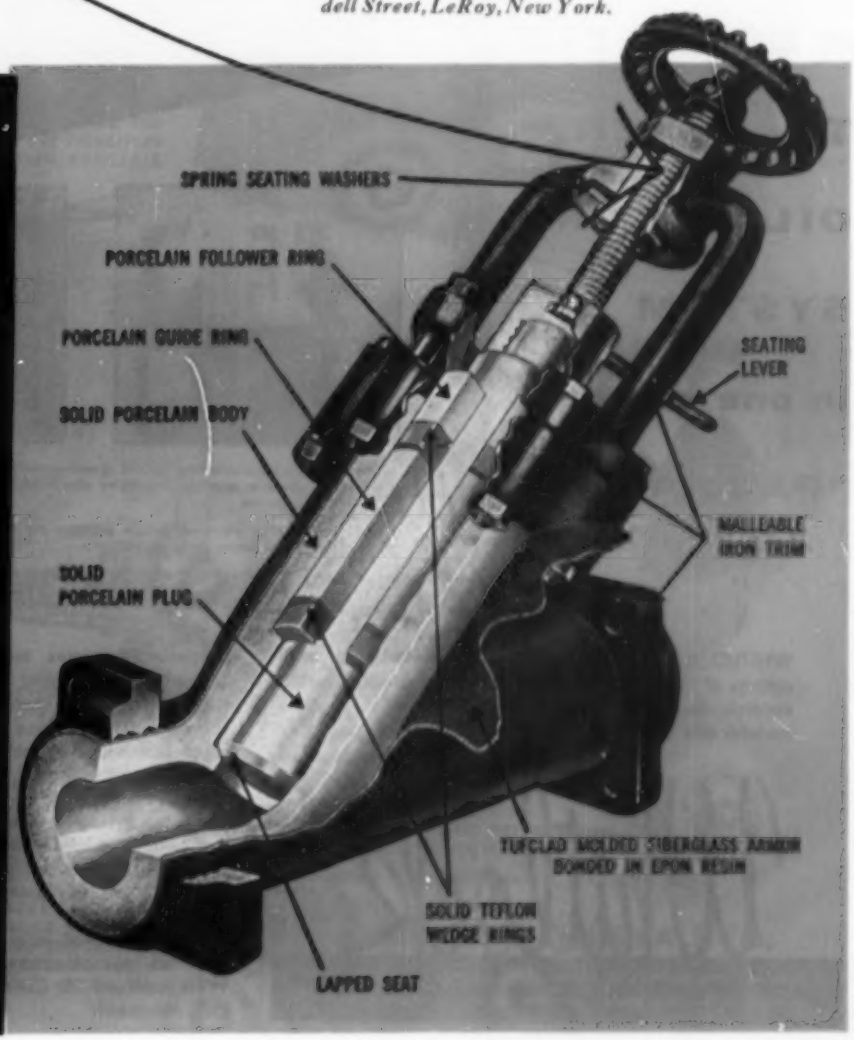

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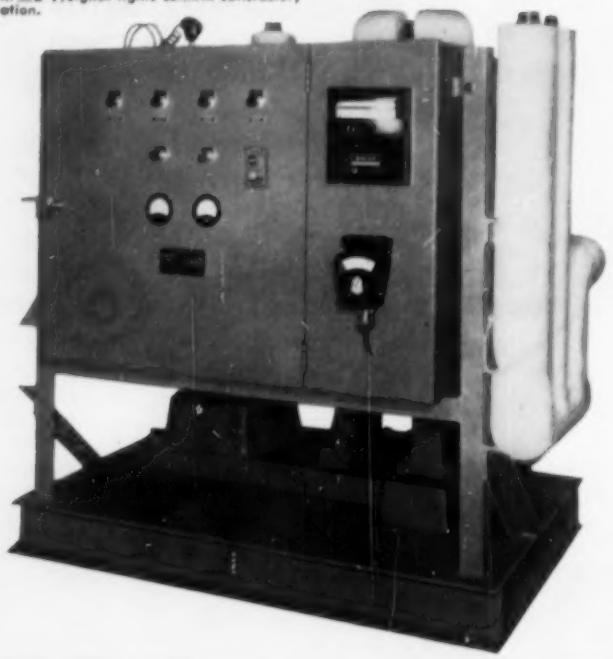

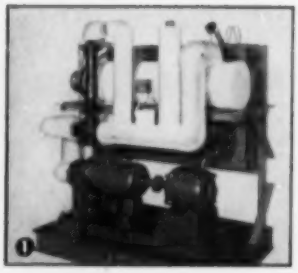

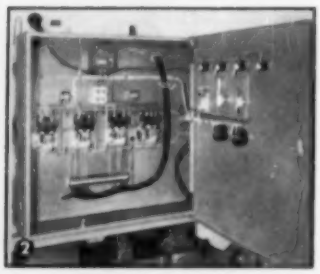

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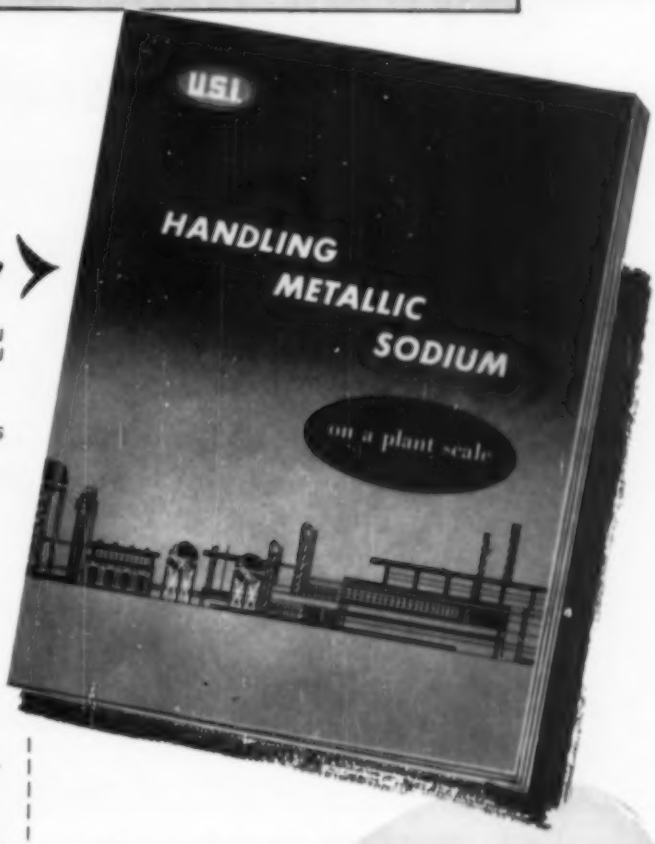

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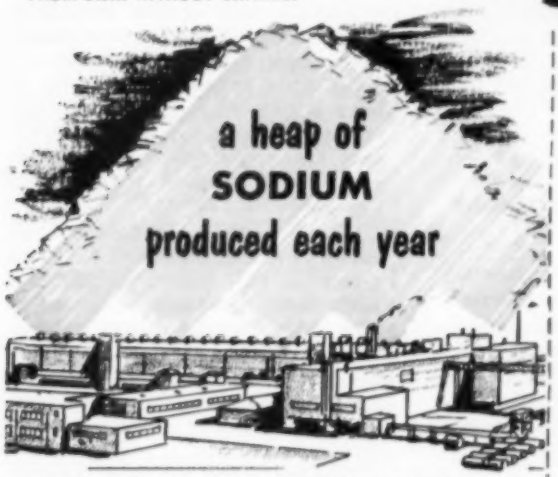

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- THAT MOLTEN SODIUM CAN BE PUMPED AND METERED CONTINUOUSLY?
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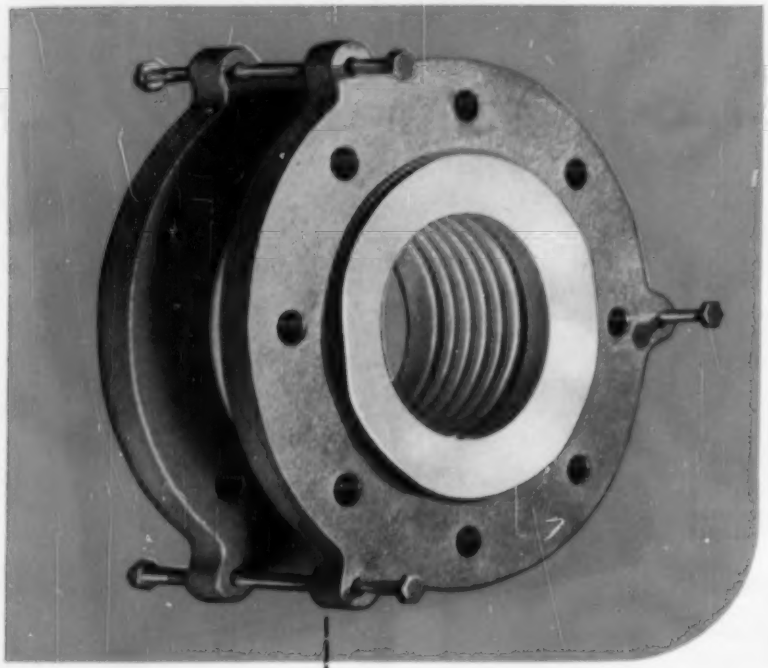

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MARGINAL NOTES

(*Continued from page 36*)

Process Engineering Economics. Herbert E. Schweyer. McGraw-Hill Book Company (1955), $7.50.

Reviewed by Charles E. Dryden, Ohio State University, Columbus, Ohio.

For a text and reference book on the theoretical and practical aspects of engineering economy this book meets a definite need in the chemical engineering profession. Those who teach this subject in the chemical engineering curriculum will welcome this book as a valuable aid in getting across to the student the basic theoretical concepts of industrial economics.

The arrangement permits flexibility for presenting whatever phase of engineering economy the instructor wishes to emphasize. Each chapter has a number of illustrative problems worked out in the main text and a large number of problems for homework assignment. Principal subjects discussed are: value of money, amortization, capital requirements, process economic analysis, and the economic balances. The last is thoroughly treated in four chapters dealing with continuous and cycle operations, yield, recovery, and inventory.

Where a more detailed analysis of a particular subject is required, one or more recent literature references are given in the footnotes. A glossary of terms is included in the appendix and this is a welcome addition as a reference. Cost data are abridged, but references for more complete coverage of their subject are listed.

What little there is on the minus side relates to format, preference for which differs for each reader. Nomenclature might have been listed at the end of each chapter instead of only three of the twelve, as mathematical equations are developed in nearly every chapter. Descriptive titles for each sample problem at the place of illustration would have been desirable in addition to tabulating the titles at the end of the chapter as the author has done. In some cases more definitive separation would have been desirable between the end of the problem and the main text. In discussing incremental costs, it would be helpful in the main text to point out that a negative value of the incremental cost is an incremental saving, and used as such in the illustration.

Book Received

Harvest of Research. The Story of The Goodyear Chemical Division. David Dietz. Goodyear Tire & Rubber Company, Akron, Ohio (1955), 54 pages.

FILTERAIDS

Paul W. Leppla, Technical Director

If your process includes a step where suspended solids – too fine to separate by settling – require removal from a liquid, filteraids may provide a solution to your problem. Chemical Engineers frequently fail to recognize potential filteraid applications, due probably to lack of familiarity with these materials.

Although there is no single typical application, a common characteristic of systems where filteraids are useful is the presence of suspended solids of natural origin, which cannot readily be characterized as to chemical composition or particle size. In fact, if you have a process liquor with less than 10% of particulates that settle out with difficulty, and whose exact nature and composition aren't known, the chances are very good that diatomite filteraids can be your answer.

In many cases the troublesome solids may be removed on a laboratory scale by filtration through fine cloth or filter paper, but the rate of filtration is reduced so rapidly by the deposition of an impervious layer of slimes, that a plant scale filtration operation operated on the same basis simply is impracticable.

The filtration engineer recognizes this situation as a "natural" for the use of a filteraid. Filteraids may be used with a variety of types of filtration equipment. The classical scheme provides for the addition of a small percentage of diatomite filteraid to the solution ahead of the filter. This is easily handled by the use of a simple proportioning feeder device.

Because of its unique porosity the diatomite "opens up" the layer of slimes as it is forming to such an extent that the flow is not choked off as the cycle progresses, and the volume of filtrate is increased a hundred-fold or even more.

The method of filteraid filtration offers the chemical engineer a process tool for clarification that is economical in first cost, operating cost, and maintenance. Cost varies depending upon the application, but filteraid addition frequently is in the neighborhood of 0.05%. Since filteraids cost 2-5 cents per pound, costs often fall into the range of 8-20 cents per thousand gallons filtered. In the clarification or polishing of relatively clear liquids, filteraid cost may fall below 1 cent per thousand gallons.

Dicalite Filteraids can give Increased clarity!

This is really an odd one. It started with a bottle of distilled water in a Dicalite laboratory, tight-stoppered in a sterile container. For certain reasons we had cause to question it. So we filtered it, using the finest grade of Dicalite filteraid—and removed microscopic solids which had survived distillation!

While this was a laboratory matter, it is of real importance to every man concerned with the clarification of process liquors, or with the separation of finely divided solids from liquids. If you require filtration so "sharp" that it will trap better than 95% of bacteria and other submicron-sized solids, there are Dicalite filteraids that do just that. Other Dicalite filteraids give faster flow-rates, yet still yield filtrates of sparkling clarity. No matter what your standard of clarity, there is a Dicalite filteraid which will meet it, or surpass it. We will be glad to advise with you on your particular process problems. Write us!

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PIONEER IN CATALYSIS

The year 1955 was notable in the drug industry for the development of many new products, for increasingly keen competition, and for shifting patterns and positions among the various firms. There were a number of instances of smaller firms forging ahead in dramatic fashion, of larger firms losing ground or at least making little major headway.

Obsolescence in the field of products is sometimes startling and a little disturbing to those who look upon the drug business as a more or less stable one. Another disturbing factor is that although the drug business is, like the chemical industry, generally considered in investment circles as a "growth industry," evidence is increasing that this is not a blanket description that can be applied to the industry as a whole, even though a few firms have made notable advances.

The hey-day of the drug industry, when industrial fortunes were made first from the sulfa drugs, then from penicillin and the broad spectrum antibiotics aureomycin and terramycin, may not have passed. But there are indications of growing competition in the year ahead.

Broad Spectrum Antibiotics

The Lederle laboratories division of American Cyanamid Co. made a cleanup by being first in the field with a broad spectrum antibiotic, only to have Pfizer hot on its trail with terramycin. These drugs were followed fast by tetracycline, which seems to be replacing the other two chief broad spectrums, putting Lederle back in the lead with Pfizer again trailing.

Then there are a number of smaller but potentially important contenders on the horizon. Chloromycetin, the broad spectrum made by Parke Davis & Co., which had a body blow some years ago when a few bad side effects appeared, has now recovered to a very substantial sales volume, approaching the present volume of terramycin, which far outsold it a few years ago.

Several new drugs not yet on the market seem also to hold reasonably important future possibilities. One of these is Upjohn's Albamycin, another Merck's Cathomycin and the third cycloserine (developed by several firms), which is expected to be of value in tuberculosis treatment as well as in some other fields. While there is no indication as yet that any of these will supplant the leading broad spectrum drugs, there is a likelihood that they will nibble away at the total volume.

Hormones

Another area that illustrates the kaleidoscopic shifting of position in the drug industry is in the hormone drugs used against arthritis. Merck & Co. had no sooner developed cortisone at huge research expense, than new competition came in with new processes and cut prices. Then last year Schering Corp. came out with Meticorten, which apparently has important advantages over the earlier cortisone drugs. This skyrocketed Schering's sales and earnings and presumably cut into the volume of other firms in the field. This year will see increasing competition against Schering from Merck, Pfizer and Upjohn in the so-called "meti" drugs. Concentrated research in the hormone field by a number of large firms indicates the probability of further important new research progress in 1956.

An example of a smaller firm that has been forging ahead in the last year or so is Norwich Pharmacal Co., which moved from a small proprietary drug company into the ethical drug field, building its progress on the nitrofurane drugs, based on furfural. This group consists of a number of drugs both for human and animal use. In the closing months of last year there were reports that Norwich had two new furane drugs in the research stage which may turn out to be of major importance for the firm toward the end of this year or in 1957.

Mental Drugs

So-called mental drugs (hypotensive agents) came prominently to the fore last year and bid fair to be of steadily increasing importance in sales volume this year. They have already caused a revolution in treatment in many mental hospitals around the country. Sales volume in this group may well reach the $50 million annual level.

One of the first drugs introduced in this field is reserpine, made from the Indian "snake root" or rauwolfia. There are now a score of firms in this field. A major early synthetic is Thorazine, made by Smith, Kline & French. Others are Vick Chemical's Meratran and Frenquel, American Home Products' Equanil and Carter Products' Miltown. It is reasonable to assume that other and better new ones in the group will be developed.

Vitamins

The old and basic vitamin business continues to grow. Large amounts are sold over the counter without prescription, but there is also a growing ethical business for treating special cases such as pregnant mothers and those in the older age groups. Severe competition has also affected this field through imports from Germany, Japan and other foreign countries.

With a contest for business on nearly all fronts in the drug field, the intensified sales efforts that appeared last year will probably be accentuated in the year to come.

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No other material of construction combines the advantages listed above with such other desirable properties as high thermal conductivity, freedom from metallic contamination, ease of fabrication and modification in the field, plus a *complete technical advisory service.* Literature furnished promptly on request.

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CEP

opinion and comment

SECRECY

A Panel * of contemporary, intelligent citizens has studied the problem of secrecy with respect to non-military information about the atom. This Panel has come forth with three important recommendations having, we believe, broad connotation with regard to governmental secrecy policies in general. The Panel's recommendations are:

1. That all reactor technology be removed by the A.E.C. from the restricted data category, including such areas as fuel element fabrication and processing techniques, leaving specific military applications of such technology under the defense classification system.

2. That the concept that atomic information in all fields is "born" classified be examined by the Joint Committee; such concept being held by the Panel as not compatible with the expeditious action required to permit rapid development of peaceful uses of atomic energy. This concept is recommended to be limited to the design, manufacture, or utilization of atomic weapons.

3. That compilation of both classified and unclassified information relating to peaceful uses of atomic energy be required by the Joint Committee to be undertaken by the A.E.C. on a continuing and current basis so that it can be available in ready reference form for those entitled to use it.

That such conclusions are sound, there should be little doubt. There is no longer time for withholding from our technologists in industry and academic institutions of research, information which since Geneva can no longer be regarded as exclusively "ours."

From another standpoint, the need for some gross changes in the rules governing classification is dictated by the monumental task of requiring qualified experts to go through each of the thousands of reports and papers which have accumulated, awaiting authorization for removal from the "born" classified status. While these papers remain in storage, industry must doubtless be making many times each day, decisions which could be made much better if proper access could be had to the total record of accomplishment to date, in non-military science and technology.

It has been said in these columns, and bears saying once again, that the engineering professions—particularly the chemical engineers—stand ready to perform the myriad functions necessary in translating the power of the atom into peaceful uses our nation can stand in initial outlay of investment, and ultimately profit from. Nothing short of a major policy on availability of information, such as recommended by the Panel, can bring this about and thus give our people the deserved product of mid twentieth-century scientific discoveries. We are referring intentionally to the extension of Panel recommendations to apply to all fields of scientific discovery, as long as the information has no bearing on national security.

Any major change in national direction, even though it be away from a rather frightening experience with governmental monopoly of scientific information, has capacity for arousing some misunderstanding. In handling the problem of the atom, Senator Anderson and his Joint Committee, and members of the Panel, are to be congratulated. The work just completed has been thorough, the mandate clear.

Now let's see the reforms put into action, and see the engineers under way!

J.B.M.

** Panel on the Impact of the Peaceful Uses of Atomic Energy to the Joint Committee on Atomic Energy.*

Senator Clinton P. Anderson (Dem., New Mexico) is chairman of the Joint Committee; Robert McKinney, publisher, Santa Fe New Mexican, chairman of the Panel. Personnel making up the panel, under Mr. McKinney, are as follows:

Ernest R. Breech, executive, Ford Motor Co.

George R. Brown, engineer & executive, Brown & Root, Inc.

Sutherland C. Dows, engineer & executive, Iowa Electric Light & Power Co.

John R. Dunning, dean of Engineering, Columbia University.

Frank M. Folsom, executive, Radio Corp. of America.

T. Keith Glennan, executive, Case Institute of Technology.

Samuel B. Morris, engineer & executive, Dept. of Water & Power, City of Los Angeles.

Walter P. Reuther, executive, UAW & AFL-CIO.

The scope of the Panel's study included a broad range of subjects, among them secrecy. The March issue of C.E.P. will review its report in total.

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plus Fast, Simplified Assembly

*excepting only hydrofluoric acid and hot caustics

"US" CHEMICAL PORCELAIN
with cemented-on ASME 125 lb. standard metal flanges

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VALVES
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Pipe and equipment to which flanges are to be affixed are formed with plain, straight ends and smoothly ground gasket surfaces. Standard flanges are of high grade cast iron, aluminum flanges are also stocked and furnished where specified. Both types comply with ASME standard for number of bolts and size of bolt circles. Extreme care is used in positioning and cementing flanges to assure perfect alignment.

Consider for a minute how your operation can benefit from the outstanding corrosion resistance and iron-free quality of "US" Chemical Porcelain Piping and Equipment . . . and the faster, simpler installation afforded by flanged fittings.

Write for Bulletin CP-50 and C-5

217-E

PROCESS EQUIPMENT DIVISION

U. S. STONEWARE
AKRON 9, OHIO

COST FACTORS in evaporator design

W. D. Kohlins

and H. P. Englander

Buflovak Equipment Division

Blaw-Knox Company, Buffalo, New York

To point out to the process engineer areas for cost reduction in evaporator design and specification is the main concern of this paper. Accompanying illustrations are convincing that the selection of proper operating conditions and a suitable flow sheet can have a major effect on ultimate costs, both investment cost and operating expense. The availability of various means of heat reclamation has been pointed out and it has been shown that specific local conditions will be the governing factor.

The evaporator manufacturer frequently is presented with a specification that would result in an evaporator needlessly expensive to purchase, expensive to operate, or both. Appreciable savings can be effected from a study of the fundamental bases for the design and the integration of this piece of equipment with present or projected plant facilities. The determination of the optimum number of effects has been covered (*1*) for conventional evaporators. There are, however, three other general areas, which will be reviewed here, that the designer must consider when studying an evaporator problem. These are physical design, flow sheet, and heat reclamation.

Physical Design

Once the flow sheet, number of effects, type of evaporator, and general specifications of heat transfer surface and vapor body size have been determined, it is important to study the other details. A case in point is the question of adherence to the A.S.M.E. Unfired Pressure Vessel Code. In many states and also with many companies, adherence to the Code is mandatory. However, depending on the materials of con-

struction, size, and other factors, it is safe to say that building an evaporator to the Code adds at least 10% to its first cost and the additional cost can easily be twice that amount. It should not be thought that an evaporator that is not Coded is not safe. Most manufacturers follow Code practices and procedures even though the final unit is not stamped, and the product is a perfectly safe evaporator built in accordance with the Code although not to the Code. Mill Test Reports, use of only Code heads, X-ray, stress relief, multiplicity of inspections, and other similar requirements of the Code all delay the manufacture and add to the cost.

Frequently some companies have special requirements of their own which are still more costly. In one case, a water quench of welded stainless steel, achieved by a stream of water immediately behind the welder, added an extra man to the welding labor required. Specification of low carbon stainless would have eliminated this. Special types of stress relief, passivation, etc., are further items that should be carefully considered before their incorporation in an evaporator specification. Therefore, when specifying the physical design of an evaporator, the matter of Codes and inspections should be given careful thought to be sure that nothing is included that is unnecessary.

Another point on the matter of physical design is the selection of proper materials of construction. This appears to be quite self-evident, but sometimes the designer does not give sufficient study to the relative costs of different materials of construction. Obviously, product quality or contamination often will eliminate consideration of all but one material. However, when it is only a matter of corrosion, several materials can be considered. Surprisingly enough, a material that lasts only a year or two can be less expensive than one that lasts five or even more years. This is particularly true in the case of evaporator tubes which can easily be replaced with relatively little down time or major construction work. Figure 1 gives curves plotting cost units against time for various materials for evaporator tubes. The accompanying Table A illustrates use of the curves. A study of the corrosion rates will give the expected life of different materials and the curve will allow selection of the most economic. The bases for the curves are shown in Table B.

It can be seen from these curves that, if it were not for the rerolling cost, if steel tubes lasted two years, they would be cheaper than any other material that lasted ten years. The cost of removing and rerolling tubes, however, makes a great difference and, naturally, this difference becomes greater as the evaporator gets larger. Hence, it can well be that the installation cost can be the governing factor.

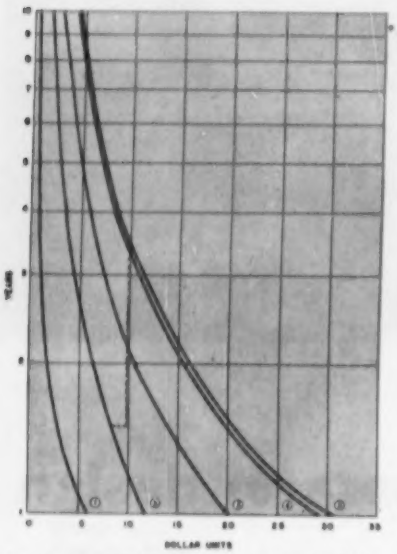


Fig. 1. Tube selection chart. 1) Steel-welded. 2) Copper. 3) Cupro-nickel. 4) St.St., Monel. 5) Nickel.

Table A.

Example:

[1a] Assumed tube life:
copper—1½ yr.
nickel—5 yr.
ratio—3½

[2a] Evaporator has 500 tubes—this adds .5 of a dollar unit for each retubing.

Solution:

a. start at 1½ yr. on curve 2
b. move horiz. to the right 1.65 dollar units (3½ × .5) for retubing costs
c. extend vertically to intersection of curve 5

Conclusion: Nickel tubes are justified since intersection point less than 5 yr.

[1a] Specific corrosion rates must be established.
[2a] Add .1 dollar unit for each 100 tubes replaced.

Another point in construction that must be taken into account concerns the physical size of an evaporator. Occasionally the size of vapor bodies gets so large that they cannot be shipped. In this case common practice has been to build dual units. However, it is decidedly cheaper to field-fabricate the larger single units than to build the multiple units. A particular case in point:

One design called for a forced circulation evaporator to have one effect 16-ft., 0-in. diam. by 20 ft., 0 in. high on the straight side. This diameter is too large to be shipped. Two 11-ft., 6-in. diam. bodies could be used to replace the one 16-ft., 0-in. unit. The two smaller units complete with steamchests, piping, and pumps cost $55,000. The single larger size cost $43,000. Allowing $5,000 for field erection, there still was a saving of $7,000 which was almost 15%. Thus, this potential source of savings must not be overlooked.

Fig. 2. Cooling water curves.

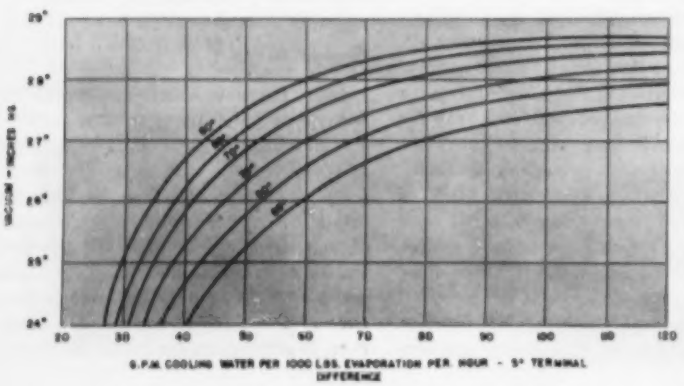
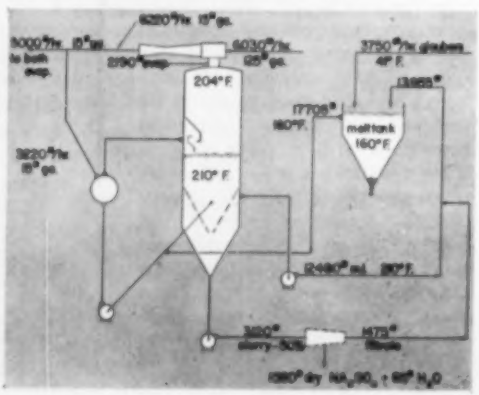


Fig. 3. Flow sheet for recompression evaporator.



MORE EVAPORATION FOR LESS MONEY

Table 1.—Specific Data and Results

Evaporator feed = 55,800 lb./hr. @ 0.06% total solids

Total heat to be transferred = Q = 12,635,000 B.t.u./hr.

% total solids	lb./hr. disch.	lb./hr. evap'n	Q/A	sq.ft. heat trans. surface required	evap. cost $
10	335	55,465	11,500	1,100	24,700
20	168	55,632	6,020	2,100	36,500
30	111	55,689	3,980	3,180	45,000

Table 2.—Tabulation of Results

	steam consumption, lb./hr.		
	acid evap.	anhy. evap.	total
conventional evaporator	5,000	3,650	8,650
operating as first effect of a double effect	2,810	4,100	6,910
recompression	0	6,030	6,030

Table 3.

steel tubes—13 gauge

all other materials—16 gauge

ratio of over-all U

stainless steel	1
Monel	1.065
carbon steel & cupro-nickel	1.08
nickel	1.13
copper	1.175

interest at 5%

Flow Sheet and Operating Conditions

Another area open to the cost-reduction conscious engineer is in the proper selection of operating conditions. Many times the process limitations are such that little leeway is left for the designer. However, here again, there may be areas not normally considered that are worthy of study. A simple case in point is the selection of the absolute pressure for the liquid side of the unit. In the case of a single or possibly even a double or triple effect, if other conditions are right, operation at atmospheric pressure in the final effect might be economic. It is true that higher pressure steam might be required and more expensive construction of the steam-chests might be involved. Balanced against this is the fact that no condenser or vacuum-producing equipment is required and consequently no constant consumption of water and power, be it steam or otherwise, for vacuum equipment. Also, steam at approximately 212° F. is available for other possible heating services. Even if conditions dictate operation under vacuum, selection of the proper vacuum can be profitable.

Figure 2 shows the consumption of water for various vacua and varying inlet water temperatures. A specific case in point:

Assume 20,000 lb./hr. evaporation in the last effect. With water at a temperature of 85° F., the water consumption for 26- and 28-in. vacuum would be 1,170 and 4,140 gal./min. respectively. With the assumption that the only cost is pumping, and the total head is 50 ft., then with power at $0.005/kw.-hr., the annual additional cost for power alone is $2,000. Also, there is the larger investment in bigger vapor bodies, bigger pumps, pipe lines, etc. Of course, against this must be balanced the saving in heat transfer surface due to the greater Δt available.

In many operations, the evaporator is merely an intermediate step followed by a crystallizer, furnace, dryer or some other processing unit. In some of these cases, the final concentration out of the evaporator is in itself not too important, but rather the combined result of several units. In a sulfate pulp mill, the concentration out of the black liquor evaporator is not critical of itself but rather the economic distribution between the evaporator and the recovery furnace that follows. An unusual illustration of this point came to the authors' attention some years back when presented with the problem of purifying a solvent. The evaporator was to furnish purified vapor feed to a still and the evaporator discharge was to be dried. The vapor from the dryer was to be recovered and the solids discarded. Evaporator tests were run to determine over-all heat transfer coefficients at different discharge concentrations. Drying tests were also run and it was found that the same size dryer would handle all the discharge from concentrations of 10% total solids and greater. The specific data and results are shown in Table 1. The difference in evaporation between 10% and 30% solids was only 224 lb./hr. but this 224 lb. required 2,080 sq.ft. of surface and cost $20,300. The proper end point could obviously be very important!

Another very different but equally important consideration is that of integrating the evaporator with other requirements in the plant. What normally would be an uneconomic design might, for certain conditions, be the optimum. A small rayon plant desired to produce anhydrous sodium sulfate from the Glauber's salt it had been discarding. Only slightly more than 15 tons/day of Na_2SO_4 were involved requiring 2,190 lb./hr. evaporation. Conventional design called for a single-effect evaporator to operate at 24-25-in. Hg vacuum. Because of a low Glauber's salt feed temperature and the large heat for melting, the steam requirement would be approximately 3,650 lb./hr. This plant also had a small acid evaporator requiring 5,000 lb./hr. of steam at 15 lb./sq.in. gauge. Thus the total steam for both units would be 8,650 lb./hr. At first it appeared that the Na_2SO_4 evaporator should be designed to operate at 15 lb./sq.in. gauge in the vapor space and its vapor used as steam for the acid unit. At the higher operating temperature the steam requirements for the Na_2SO_4 machine would be 4,100 lb./hr. This, plus the 2,810 lb. of make-up steam required for the acid unit, resulted in a total steam consumption of 6,910 lb./hr. and also a rather complicated evaporator hook-up.

A third alternate was the one finally selected. This is as shown in Figure 3. In this system the Na_2SO_4 unit had a recompression booster which compressed all the vapor to 15 lb./sq.in. gauge. The conditions and design of the booster were selected so that the

Table 3.—Basis for Calculation = 3,000 operating hr./yr.—5 years' capital recovery

	double-effect steam evap.	NH_3 refrig-eration	mechanical recompres-sion
lb./hr. steam	11,675	1,000	600
gal./min. water	1,505	222	200
hp.	57.5	494	624
utility cost—cents/gal.	2.06	1.10	1.27
annual cost, total investment	198,000	262,000	252,000
total cost—cents/gal.	5.3	5.4	5.6

booster discharge furnished sufficient steam for both evaporators. The total input of steam was thus 6,030 lb./hr., and a simple evaporator design resulted.

A tabulation of the results is shown in Table 2.

Here again, the integration of the evaporator into the total plant requirement resulted in a better and cheaper design.

Heat Reclamation

Another technique open to the designer who wants to achieve economic evaporator operation involves the reclamation of heat in various forms. Some methods, such as using condensate for heat exchange with cold feed or similar types of conventional heat reuse, are quite common. There are, however, other means that are not so frequently considered. One case in point is the use of condenser tail pipe water. In an evaporator operating at 4 in. Hg abs. pressure, this water can be kept at 120° F. Many plants require hot water and here is a source of preheating. Consider a condenser discharging 2,000 gal./min. of water at 120° F. For every 10° F. this water is cooled, 10,000,000 B.t.u./hr. are recovered, equivalent to approximately 10,000 lb./hr. of steam. Even though this is at a low-temperature level, there are cases where it can be used effectively, particularly if the plant has a requirement of large amounts of hot water.

Another tool of the designer that is coming into more prominent use is vapor compression in some of its various forms or the true heat pump. Nowhere did this show up more advantageously than in the thousands of potable water evaporators built for the Armed Forces during World War II. A more recent example of this type of design was the field of low-temperature citrus-juice concentration. Here, units were designed with the use of steam recompression, mechanical recompression, and the heat pump. Local conditions governed which was the more economic. A specific case will serve to illustrate this point.

The details are as follows:

Required to concentrate 1,610 gal./hr. of orange juice from 11 to 58° Brix at low temperature and then cut back to 42° Brix. This is equivalent to 11,340 lb./hr. of evaporation.
steam cost = 52.2 cents/1,000 lb.
water cost = 2 cents/1,000 gal.
power cost = 1 cent/kw.-hr.

Costs were then compared between a double-effect recompression steam evaporator, a mechanical compression unit using centrifugal compressors, and an ammonia refrigeration system. Construction was to be of 304 stainless steel and of sanitary design. The results are summarized in Table 3.

In this case the total cost per gallon was approximately the same although the utility and investment costs were very different. Different basic conditions could make a great change in the final result.

A completely different type of operation was encountered in a chemical plant where it was required to concentrate to saturation 1,000,000 lb./day of a waste metal sulfate solution that was fed to the system at 176° F. Two units were compared, a quadruple-effect conventional steam evaporator and a two-stage mechanical compression unit. The basic data are given in Table 4. The resulting comparison between the two units is shown in Table 4A.

Table 4.

Required evaporation	= 40,600 lb./hr.
steam cost	= $0.60/1,000 lb. @ 190 lb./sq.in. gauge
water cost	= $12/1,000,000 gal. @ 75° F.
power cost	= $0.0046/kw.
interest, depreciation & maintenance	= 15%/yr.
operating time	= 8,000 hr./yr.

Table 4A.

Quadruple-Effect Steam Evaporator		
steam	= 11,750 lb./hr.	= $56,400/yr.
water	= 555 gal./min.	= 3,200/yr.
installed cost	= $129,000	= 19,350/yr.
	total cost	= $78,950/yr.
Two-Stage Mechanical Recompression		
power	= 1,100 bhp.	= $30,200/yr.
installed cost	= $182,000	= 27,150/yr.
	total cost	= $57,350/yr.

Thus, in this case the mechanical unit, although 40% more expensive to install, was the more economic.

Summary

It has been shown that physical design of any unit must be given careful study. Specifically, it was brought out that in one instance mechanical compression was much more economic than a multiple-effect steam unit, whereas in another case, the costs were substantially the same. In summary it can be stated that there are many avenues open to the experienced designer to achieve economical evaporator costs, and unusual avenues must not be overlooked when studying the complete evaporator problem.

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MORE EVAPORATION FOR LESS MONEY

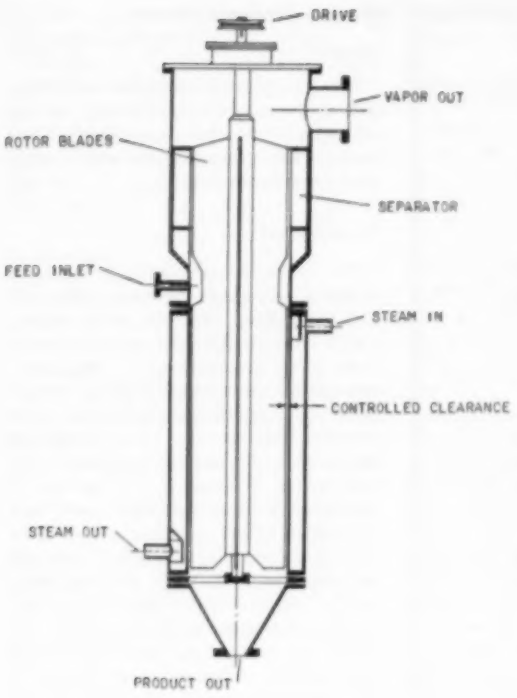

Fig. 5. Rodney Hunt Turba-Film evaporator.

selection and application of EVAPORATION EQUIPMENT

Malcolm M. Coston and E. Ernest Lindsey

Evaporator selection with its application is an integration of solution characteristics, evaporator-type characteristics, and the economics of capital equipment and operating costs. The engineering choice is influenced by physical properties of the solutions to be evaporated (viscosity, density, solubility of solid content, surface tension, boiling-point rise, etc.); by utilities cost data and cost assumptions; by equipment installation and maintenance costs; by costs of labor, power, fuel or steam, cooling water; by plant energy balance; by equipment characteristics (tube lengths, tube diameters, velocities, materials of construction, etc.). These variables cannot truly be separated for investigation because of their influence on one another. Choice of an exact optimum from such an imposing list is practically impossible without reference to specific cases which will be done in this paper.

Evaporation is defined for the purposes of this discussion as the removal of a solvent by conversion to the vapor phase from a relatively nonvolatile solute, usually a solid. Except for those cases where a salt is precipitated, the solvent is usually not completely removed. Evaporation requires the addition of heat and the separation of vapor and liquid. This paper will be limited to applications and equipment in which heat is supplied through solid walls by condensing vapor, i.e., the usual commercial evaporator and related equipment. Related equipment can be described as pumps (*4*) separators (Figures 1A, 1B, 1C, 1D) condensers (Figures 2 and 4) and ejectors (Figure 3).

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Evaporator Types (1)

Most newly purchased evaporators today take one of two forms: They are (1) natural circulation, and (2) forced circulation. These account for the bulk of evaporation applications. However, there are some newer types getting more frequent use for special applications such as the Turba-Film(R) evaporator, an agitated-film evaporator for viscous and/or heat-sensitive materials, and the Rosenblad switching evaporator for scale-forming liquids.

The agitated-film evaporator (Figure 5) consists of a vertical heated cylinder containing a rotor. The rotor is provided with blades which approach the heated cylinder walls with controlled clearance. Little liquid is contained in this evaporator during operation and the time of liquid contact is short permitting the evaporation of highly sensitive materials. The generated vapor passes through a catchall similar in design to the impact unit of Figure 1C, which is part of the rotor assembly.

The Rosenblad switching evaporator is unique in that the heat-transfer surface is constructed of special flat plates with spacers separating them. These plates are bolted together in groups or pairs, and one side of each plate can be used as a steam-condensing or as a liquid-evaporating surface at will. For scaling materials, this arrangement permits a scaled surface to be washed with wet steam and condensate with a possibility of dissolving the scale.

The short-tube horizontal evaporator is the last commercially significant design with steam inside the tubes. The coil- or bent-tube design usually disposed horizontally is generally considered obsolete. It has been retained in marine use because of the particular scale deposition problem and because of the ability of the coil or tube to change shape with extreme temperature changes. This "cold shocking" is effective in cracking scale and making the surface easier to clean.

Other natural-circulation designs are the short-tube vertical and long-tube vertical evaporators. The names describe the disposition and relative length of tubes. This long-tube vertical design can be put to either rising- or falling-film use.

The forced-circulation design is characterized by a pump which generates the flow across the heat-transfer surfaces. These may be either the vertical-tube type which is usually single pass or the horizontal-tube type which is generally used when multipass operation is indicated or desired.

These various types of evaporators have different applications which are controlled by solution characteristics to a great extent and by plant considerations to a minor extent.

AUXILIARIES | TO BE CONSIDERED AS PART OF THE ECONOMIC PICTURE

SEPARATORS

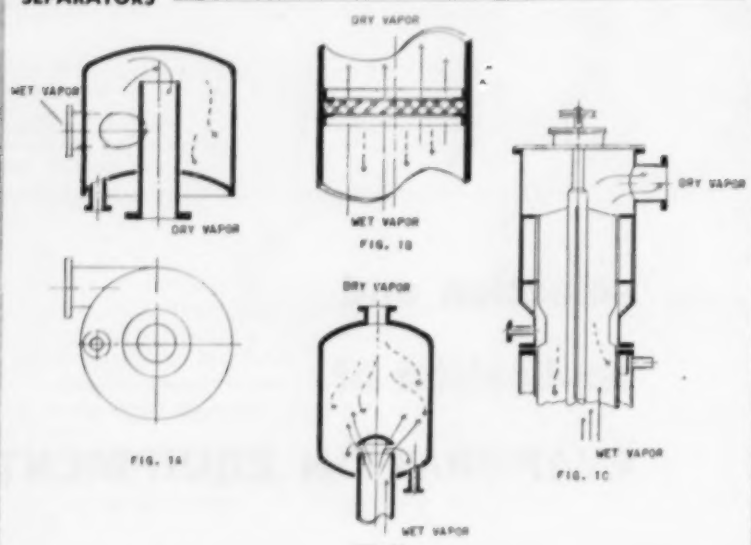

Fig. 1A—Centrifugal. High vapor velocity. Fig. 1B—Impact (porous barrier). Medium vapor velocity. Fig. 1C—Impact (rotating baffles). Best for foams. Fig. 1D—Volumetric. Where volume is adequate.

CONDENSERS

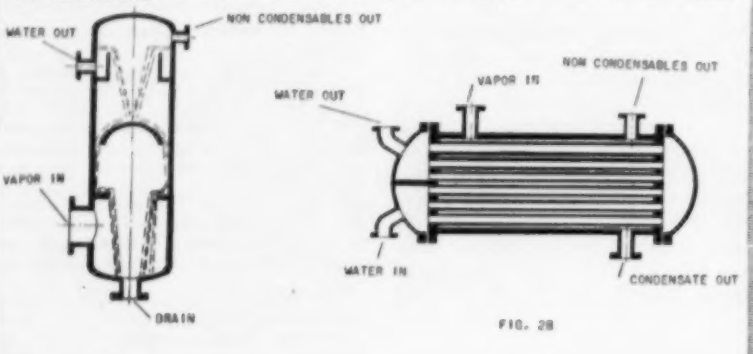

Fig. 2A—Direct contact. Generally preferred. Fig. 2B—Surface. Where contamination is important.

VACUUM PUMPS

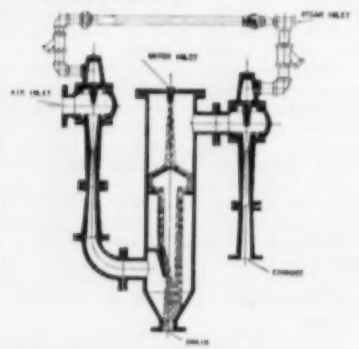

Fig. 3. Ejector. Relatively inexpensive, simple, and trouble-free.

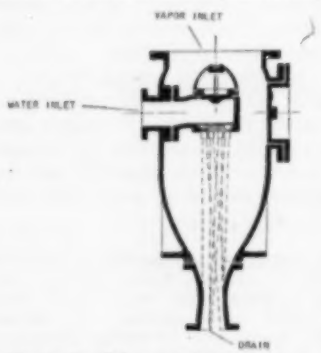

Fig. 4. Parallel current barometric condenser. For combined handling of vapor and noncondensables.

Choosing Evaporator Bodies

VISCOSITY

For straight concentration problems with a *moderate* viscosity change and no salting, all types mentioned can be used on the assumption that scaling is moderate or nonexistent.

100 centipoises

For straight concentration, up to a viscosity of about 100 centipoises and with no salting, the long-tube vertical (LTV) evaporator, the short-tube vertical (STV) or calandria evaporator, and the forced-circulation (FC) evaporator can be used. Again scaling is assumed moderate or nonexistent. It should be noted that the horizontal-tube type is not eliminated, but its cost is usually high except in copper and cast-iron construction.

In concentration with coincident salt precipitation and with the solubility curve of salt rising with temperature, *batch* evaporation can be handled in the short-tube vertical or the forced circulation design. *Continuous* evaporation is best handled in the forced-circulation design.

For concentration with scaling, and with or without salt precipitation, the forced circulation evaporator is generally used. In this case, the salt being precipitated may have either a standard or inverted solubility curve.

6-100 centipoises

For concentration to moderately viscous products (6-100 centipoises), without scaling, the forced circulation, falling film or agitated thin layer (e.g., Turba-Film) types are recommended.

greater than 100 centipoises

For concentration to extremely viscous products (>100 centipoises) the only available equipment is drying equipment (drum dryer, shelf dryer, etc.), slow evaporation from an agitated kettle, or the agitated film-type evaporator.

HEAT SENSITIVITY

For concentration of heat-sensitive materials, evaporation at low temperature (high vacua) is recommended with the use of the conventional falling-film, or forced-circulation types. As an alternative the use of the agitated-film evaporator operating at the same low temperatures or at higher temperatures may be desirable. The agitated-film type minimizes the time at temperature because of its continuous evaporation with low holdup and of the minimized boiling film heat-transfer resistance caused by

the extreme turbulence in the highly agitated thin layer.

Finally the choice is modified to a great degree by other physical properties of the solution, as already noted, and upon the materials of construction. Minor influences are the powerhouse heat balance and the size of the whole installation.

Small Plants

Smaller plants can tolerate lower equipment availability or conversely more time for cleaning by the simple expedient of making the equipment slightly larger than required for the job. From the equipment manufacturer's standpoint, this is fairly easy to do in small sizes because the engineering and labor required for a slightly larger unit are not much more and result in a somewhat excess capacity design. There is a tendency, therefore, for the small plant to use the less complex systems even on difficult problems and allow more time for shutdown and cleaning to maintain the heat transfer rate.

Conversely, large plants can use and pay for complex systems to gain continuity of operation and increased economy.

Optimum Number of Effects

In the black liquor problem it was noted that type selection was influenced by the desire to provide as many effects in the operation as possible. Selection of the number of effects for a given duty is purely and simply an economic consideration because as the number of effects increases, the cost of the installation increases (*2*). Conversely, as the number of effects increases, the total steam consumption of the system decreases.

Although there are many ways of getting a quantitative answer, perhaps the most realistic is to start with one-effect system and add effects one at a time seeking the answer to the question "Does the yearly steam saving for this extra effect promise to pay for it in a reasonable time?" If not, the addition of more effects can be eliminated from consideration. Because accounting practices vary widely among companies, it has been the custom of equipment makers to use a two-year payoff period. This simply means that the value of the steam saved for a period of two years should be equal to or more than the cost of the capital equipment necessary to effect the steam saving.

As previously noted, the cost of the equipment varies as a function of the material of construction. After the material has been selected and the cost of one effect estimated, the cost of increasing the number of effects can be roughly stated by the equation $V = CN^{0.75}$,

where

V = total capital cost of the installation
C = cost of one effect
N = total number of effects in the installation.

Likewise, a rough estimate of steam consumption is satisfactory at this point. Neglecting the effect of pressure on latent heat and also neglecting the effect of feed temperature one can rough out the steam consumption of evaporators by the figures in Table A (next page), which are perhaps a bit conservative.

Examples of Evaporator Selection

1. Influence of these variables on evaporator selection—evaporation of *fish stick water* will be considered. "Stick water" is a solution of fish solubles and fine fish meal resulting from the cooking of fish for oil recovery. It is a good feed additive because of its high vitamin content and is a relatively valuable product for recovery.

This solution can be handled in all types of equipment. However, scaling is present in all cases. The long-tube vertical and forced-circulation designs require stainless steel tubes because of the high tube velocities and consequent erosion and corrosion. The short-tube vertical and the horizontal designs can use 90-10 cupro nickel tubes because here the velocities are relatively low. Although coefficients on the short-tube vertical and the horizontal design are lower, requiring somewhat more surface, the net cost of this equipment is less because of generally cheaper construction and elimination of large forced-circulation pumps. It would, therefore, be the choice of the small plant to use the short-tube vertical or horizontal evaporator. The large plant, because of higher throughput, needs a higher availability and, as costs tend to converge with large sizes, the forced-circulation design with stainless steel tubes and a low fouling factor is justified.

Both small and large plants can obtain greater availability and capacity by using an agitated-film evaporator as a finishing unit. This unit can handle the viscous thick liquors above 30% without scaling because of the extreme agitation.

2. Alum production—this comprises the evaporation of a solution which is corrosive. The final concentrated product is a metastable liquid because the residual water is insufficient to supply the demands of the hydrated salt. Cooling produces a solid crystalline or glassy product. Less concentrated solutions would also crystallize if temperatures were allowed to fall. Moreover, the final product is viscous. Because crystallization can occur if residence time is long enough, the volume of product in the evaporator should be minimized. Although the viscosity of the product would indicate the use of the forced-circulation type, the requirement of minimum volume forces the selection of the long-tube, vertical single-pass design.

3. "Black liquor"—this is the liquid resulting from the Kraft wood-pulp digestion process. It is a foamy liquid with a relatively wide viscosity change on concentration. It is reasonably noncorrosive to steel and has recoverable material of some value. As the equipment can be primarily of low-cost steel construction, and as steam cost reduction is mandatory in the marginal economics of the recovery, multiple-effect operation is indicated. The optimum number of effects is controlled by the available extraction steam pressure at the powerhouse turbines *provided* equipment is selected which will operate on the lowest temperature drop (Δt) per evaporator unit. The requirement of low Δt can be met with either the long-tube vertical or the forced-circulation types. In steel construction, the long-tube, vertical design is less expensive per unit of evaporation *for this liquid* and hence would be the choice.

4. Orange juice concentration—this material requires careful attention because of the heat sensitivity shown during concentration. Short exposure time is an advantage, even at low temperatures. These two solution characteristics have led to the wide use of the falling-film evaporator. Subsequent studies and commercial operation have shown the need for recirculation of concentrate to maintain wetted-tube surfaces and the loss of some of the advantages sought in the falling-film design. Continuing studies indicate that the single-pass operation possible in the agitated-film unit will restore the advantages of the falling-film design.

Table A.

No. of Effects	lb. of Water Evaporated by 1 lb. Steam
1	0.75
2	1.2
3	2.1
4	3.0
5	3.5
6	4.1

The effect of feed temperature cannot be too clearly generalized, although it can be said that a high feed temperature increases and a low feed temperature decreases the economy, mainly because of the requirement of supplying sensible heat or the availability of sensible heat for self-evaporation. Feed temperature also determines the point of introduction of feed to a multiple system. Economies can sometimes be enhanced by feeding into that body which is nearest to the feed in operating temperature. Again, this cannot be made a generalization because of the temperature variation of viscosity. With caustic soda, for example, the total heat-transfer surface can be reduced somewhat if the more dilute lower viscosity liquids are handled in the lower temperature effects. The high viscosity strong liquor is usually handled in a higher temperature effect because its viscosity at the elevated temperature is less than if the solution were handled elsewhere in the system.

Data Required

The data required for a complete evaporator problem solution are many. Some are known to be available from equipment makers; some must be supplied by the user. Equipment manufacturers generally have quite complete data on the more common solutions used. Usually these are:

1. viscosity over a range of both temperature and concentration.
2. heat capacity over a range of concentration; temperature variation is usually not too important.
3. heat of evaporation (latent heat of vaporization from solutions)
4. heat of solution (opposite of heat of concentration)
5. if solids are precipitated, heat of crystallization
6. thermal sensitivity to decomposition, flavor loss, bacterial growth, etc., with respect to concentration, time, and temperature; this is becoming more and more important with foods, antibiotics, pharmaceuticals, etc.
7. boiling-point elevation of solution over a range of concentrations and temperatures if available; usually this is represented by a Duhring line chart.
8. scaling characteristics, either experienced or expected.
9. solubility curves vs. temperature and concentration if multiple salts or hydrated salts are produced.

In addition to these general data, there should be available from either the manufacturer or user:

10. consistent or steady-stream pressures.
11. cost of steam.
12. maximum cooling water temperature or better, the seasonal variation.
13. cost of cooling water.
14. cost of power and power characteristics.
15. recommendations on materials of construction (as an aside, everyone wishes to build equipment which will last essentially forever. However, it may be better to select materials which have only a reasonable life, are cheaper, and are more available and easier to fabricate).
16. space available including headroom.
17. complete analysis of feed and final products.
18. Any comments on peculiarities of the solutions. (Sometimes peculiarities are observed by individuals and given no particular attention until it is found that this peculiarity either prevents the equipment from reaching capacity or increases maintenance.

Summary of Selection Procedure

In selection of an evaporator, one should proceed as follows:

1. Examine the scaling characteristics of the solution.
   (a) Is it a bad scaling solution? If so, eliminate natural circulation immediately and proceed to forced circulation, or the Rosenblad design if scaling is unusually bad.
   (b) If it is not a scaling solution, does it have a large increase in viscosity? If so, one can eliminate the short- and long-tube and horizontal, natural-circulation designs, and retain forced-circulation and agitated-film designs.
   (c) If there is minor viscosity variation, then one is unlimited and can use any design selecting, of course, the least expensive.
   (d) Is a salt or other solid to be precipitated during solvent removal? In general this eliminates the short-tube, horizontal, or falling-film designs but retains the possibility of the forced-circulation or agitated-film design. If controlled crystal size is important, the agitated-film design is eliminated.
   (e) Is the solution heat sensitive? If so, any unit which has low coefficients or large operating volume should be eliminated. The falling-film or agitated-film designs should be retained with a possibility of a carefully designed forced-circulation unit.
2. After selecting the type, the next step is to select number of effects, using rough figures given earlier.
3. After number of effects are roughly chosen, a careful heat balance is run on this number to check the assumption of economy which was used in 2. It is not expected that this economy will vary greatly, but sometimes radical changes in feed temperature will make the economy change enough percentagewise to justify recomputing the number of effects.
4. After the final heat balance a careful calculation of heat-transfer requirements is in order. Where the effects are all the same general type, it is customary to design for equal heat-transfer surface in each. From a fabrication standpoint, it is easier and cheaper to fabricate four bodies which are similar in every respect than four different size bodies. Unbalancing of heat-transfer surfaces is sometimes necessary, though, to protect solutions which have delicate constituents sensitive to heat and also in the case of rubber-lined equipment where the maximum permissible temperature is about 185° F.

Computation of heat-transfer surface is purely and simply based on experience except for forced-circulation evaporator. In the latter, boiling is suppressed and coefficients can be calculated based on the Dittus-Boelter equation for heating liquids. Where boiling occurs during heating there are at present no known correlations which are consistent, although perhaps Rohsenow's equation (*3, 5*) is the best. Thus the designer must depend on the experience of his own company or equipment manufacturers or upon as near full-scale pilot operation as possible. By this is meant that the pilot plant, although reduced in capacity, should be physically designed to simulate the final commercial equipment as close as possible, and that the same liquid solutions be used.

After selection of heat-transfer surface area, it is possible to develop the physical dimensions of the equipment and finally to select the auxiliaries.

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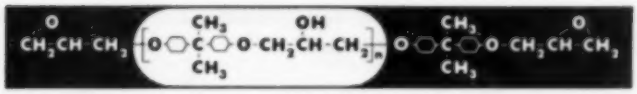


Figure 2.

C. V. Wittenwyler | Shell Chemical Corp. New York

using the epoxy resins

The epoxy resins, basically a new type of resin for coatings and plastics applications, have been available commercially for only five years. Since their introduction in 1950 by Shell Chemical Corporation under the trade name Epon, they have been widely accepted and are now among the fastest growing plastics. Their rapid acceptance and growth are due largely to two features: (1) their unique combination of physical, chemical, and electrical properties, and (2) the ease with which they may be formed into many useful products.

Only twenty years ago the plastics industry was in its infancy; and yet today it is one of a few industries selling over a billion dollars worth of product a year. The plastics industry is now the largest single consumer of organic chemicals and is still growing at a steady rate. The volume of plastics sold has doubled every five years. The first class of synthetic resin made, the phenol-formaldehyde resins, is still sold in large quantity.

The phenolic resins are excellent resins when properly used but would be woefully inadequate if they were the only resins available for all the plastic needs today. The vinyls, for example, are needed to provide flexible resins, the acrylates for water clear resins, the nylons for fibers, the styrenes for rigid moldings, and the alkyds for coatings.

The increasingly specialized uses for plastics have caused a growing need for new and improved materials. The ability of the plastics industry to recognize and meet the more demanding consumer needs by developing new resins is largely responsible for its continued success. The epoxy resins are the newest of these developments in the search for better plastic products.

The epoxy resins, and there are several members of this class, are all light amber-colored materials, some liquids and some solids. The end-use to which they are put usually determines which form is preferred. Their properties are shown in Table 1. Curing converts them to thermosetting resins which can thus be used at elevated temperatures. The epoxies are completely unrelated to any other previously used plastic. They are made from bisphenol and epichlorohydrin according to the reaction shown in Figure 1. Both of these are rather obscure, but plentiful starting materials are made from fractions of petroleum. Their name is derived from epoxide groups they contain. The general chemical structure of these resins is shown in Figure 2.

The epoxide groups also explain their particular chemical nature and special type of curing. Epoxy resins may be converted without heating from liquids to hard, tough plastics by mixing in a small amount of amine curing agent.

Since their introduction, these versatile resins have found wide use in paints, varnishes, and enamels for nearly every type of coating used by industrial and home consumers. They are also used in structural plastics, as castings, laminates, and adhesives.

Coatings are used for household paints and varnishes, food-can linings, industrial-maintenance paints, corrosion-resistant primers, chemically resistant equipment enamels, and wire enamels.

Laminates are used to make printed circuits, radomes for housing aircraft radar sets, storage tanks, and high-strength, corrosion-resistant pipes.

Castings are used to pot or encapsulate electronic circuits for protection from moisture, shock, and vibration; and in tooling, to make dies used to form sheet metal.

Adhesives are used in many applications, but their wide use in aircraft structures exemplifies their high strength and dependability.

Epoxy Coatings

At present the epoxy resins find their greatest use in the field of surface coatings to protect and enhance the appearance of all types of surfaces. They can easily be made into air-dried or baked enamels for indoor or outdoor use. They can be applied by brush or spray over metal, wood, concrete, plastics, or paper. All epoxy coatings show a high degree of flexibility, adhesion, and chemical resistance. Sheet metal coated with epoxy resins can be folded double without cracking the epoxy film. The coating shows sufficient adhesion that the coated metal may be stretched, punched, crimped, stamped, and nicked without film failure. These films, though often less than two thousandths of an inch in thickness, resist the effects of acids and bases at room temperature and high temperatures as well as the effects of strong solvents. Though many of the synthetic resin coatings made today resist one or more of these destructive agents, the epoxies represent a closer approach to the universal finish by providing a broader range of protection.

Most epoxy coatings are quite similar in application to conventional paints. However, their use has led also to a new type of paint employing an epoxide cure. Unlike other paints that depend upon solvent evaporation or air oxidation for their drying qualities, this coat-

Primary Epoxy Resin Properties

- good cures at low temperatures
- low shrinkage during cure
- excellent adhesion
- broad spectrum chemical resistance
- good electrical properties
- very good flexibility
- high solvent resistance
- wide control over product properties

Figure 1.

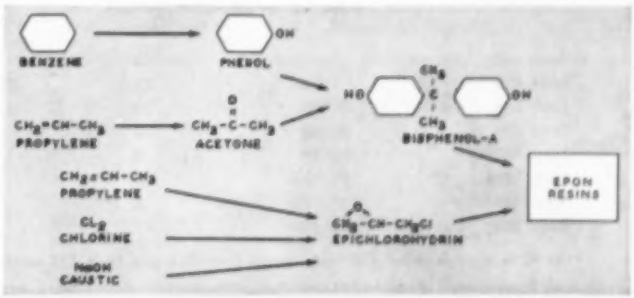


Table 2.—White Enamels for Home Appliance Application

	Hardness	Alkali resistance	Yellowing at 300° F.	Weathering durability	Flexibility	Net rating	Cost index
Alkyd	Poor	Poor	Poor	Good	Good	26	3.4
Alkyd-urea	Good	Poor	Fair	Good	Good	37	4.5
Alkyd-melamine	Excellent	Fair	Good	Good	Good	52	5.5
Epoxy-melamine	Excellent	Excellent	Fair	Good	Excellent	60	6.0
Vinyl	Fair	Good	Poor	Fair	Poor	34	5.7
Methacrylate	Poor	Poor	Excellent	Fair	Good	44	11.5
Silicone	Good	Excellent	Excellent	Good	Good	64	100

ing depends upon neither. The paint dries chemically by the addition of an activator. Before use, a small amount of an amine activator is stirred into the paint. After it is applied, it sets up chemically to a hard, tough coating which withstands the effect of weather, chemicals, and solvents. This special type of coating was developed to meet the demand for a coating that had the qualities of a baked film yet required no heat for hardening.

Many items such as large tanks, wood floors, steel structures, and concrete and plastic materials cannot be baked, either because of their size or heat sensitivity, but still require the protection of a baked type of coating. They may be readily coated now with this cold-cured paint and still enjoy most of the benefits of a baked finish. The epoxies are the only class of resins that will cure in this way.

At Crane Co., Chicago, Epon® resin is used in three formulations for casting, molds, and mold cores to make patterns for valves and other equipment. Shell photo.

This amine-cured epoxy finish has been used successfully on chemical plant structures and equipment. For example, one chemical plant which is exposed to the effects of high humidity, hydrochloric acid, and chlorine gas was troubled with severe corrosion losses. Conventional paints all failed rapidly in six months or less. The cold-cured Epon resin finish was tried and has lasted more than two years without failure. Similar success has been achieved in coating off-shore drilling rigs used in the Gulf of Mexico. Salt-water immersion makes this a severe test for any coating. The epoxy coatings have provided excellent protection from corrosion. This type of epoxy coating is used also to protect the Douglas DC-6 and DC-7 aircraft used by many airlines throughout the world. Few coatings show good adhesion to aluminum; and on aircraft the life of a film is shortened further by the hydraulic fluid occasionally sprayed on the coating, the hot exhaust gases from the engine, the deicing fluids used, and the erosive effects of raindrops at 350 miles/hr. Three hundred paints were tested but only one, an amine-cured paint based on Shell's Epon 1001 resin, gave complete protection after 1,000-hr. service.

The other, more conventional types of epoxy paints and enamels have been just as impressive in their performance as this new type of paint in providing more lasting protection and better appearance. A summary of their performance and relative cost is shown in Table 2.

Epoxy Laminates

The properties which make the epoxy resins successful in surface coatings have also made them of special value in laminates. Laminates, made by bonding together sheets of cloth, paper, asbestos, or other material with resins have been known for a long time.

They are made by saturating the sheets with the resin, then curing the resin in a press with the use of heat and pressure. Formerly resins used in making laminates required pressure of 1,000 lb./sq.in. or more to cure them properly. This high pressure required large presses to make laminates of any size. Such presses were expensive, and consequently laminates were limited to small sizes. Recently, low-pressure laminating resins have been developed which can be used at pressures of 25 lb./sq.in. and lower.

The epoxy resins are low-pressure resins, and large area laminates can be thus made in moderate capacity presses.

The epoxy resin laminates are normally made with glass fibers as the reinforcing material. These laminates are generally used as high strength or electrical laminates rather than for laminated plastic automobile bodies or for contour furniture. Their excellent electrical properties make epoxy laminates ideally suited to printed circuitry for

Table 1.—Properties of Epon Resins

	Softening point, ° C.	Color,* (Gardner) max.	Viscosity,* (Gardner)	Wt./epoxide	Equiv. wt. for esters
Epon 562	liquid	5	C–F	140–165	65
Epon 828	8–12	12	(50–150 poises)	190–210	85
Epon 834	20–28	10	A_2–A_3	225–290	105
Epon 864	40–45	8	A_3–B	330–375	115
Epon 1001	64–76	8	C–G	450–525	145
Epon 1004	95–105	6	Q–U	870–1025	175
Epon 1007	125–132	8	Y–Z_1	1650–2050	200
Epon 1009	145–155	11	Z_2–Z_3	2400–4000	220

* On 40% solution in butyl carbitol except Epon 562 and Epon 828 which are undiluted.

radar and electronic circuits, and for radome housing in aircraft.

The tensile strength of these fibers is over 250,000 lb./sq.in. It has been found that more of the benefits of the glass fibers are utilized in epoxy resin laminates than for other resin laminates because of the better adhesion of epoxy resins to the glass, their lower shrinkage during cure, and their ability to "wet" and bond the fiber more completely. This effect is shown in Table 3.

These epoxy-glass cloth laminates have less than ¼ the weight of structural steel, yet the same magnitude of tensile strength: on an equal weight basis, the epoxy laminates have a tensile strength five times that of structural steel. In addition, they do not corrode from the effects of exposure or chemicals, they are easy to fabricate and assemble, and never need painting. Experimental Epon resin laminates have shown exceptional service at temperatures up to 500° F. After 200 hr. at 500° F., these laminates have flexural strengths as high as 36,000 lb./sq.in. Laminates showing this particular high-heat-resistance quality are of interest to the Air Force as structural materials for aircraft. As aircraft speeds advance beyond the speed of sound, skin temperatures of 500° F. will be generated just from air friction. Both aluminum and magnesium suffer a marked reduction of strength above 300° F., so new materials of construction must be found. In this field, light-weight, high-strength, heat-resistant Epon resin laminates are being studied intensively and show much promise.

Storage tanks have been made from staves of epoxy-glass laminates. Tanks as large as 500-bbl. capacity have been put in service in petroleum and chemical storage. Their light weight permits savings in freight costs and simplifies construction. Because of their resistance to atmospheric corrosion, these tanks require no painting and little upkeep. They are not attacked by acids or other corrosive chemicals as steel tanks are.

Test strips show no significant change in weight or flexural strength after 3 hr. in boiling acetone or water. Though more expensive initially than steel tanks, their longer service life is expected to make them more attractive for many applications.

Another type of epoxy laminate made in the form of a pipe shows promise for use under corrosive conditions in the process industries. Now in the development stage, this new kind of pipe is made by winding glass fibers around a mandrel of appropriate size.

The layers of glass fibers are then thoroughly saturated with the epoxy resin; and, when the desired thickness has been built up, the laminate is cured with heat. The tube is then slipped off the mandrel and is ready for use. Because these epoxy pipes are a new development, the data available on their properties are limited; however, it is clear that they will permit higher temperatures and greater operating pressures than presently used extruded plastic pipe. The epoxy pipe may be used in a wide variety of services involving corrosive chemicals, acids, bases, and salt water.

Another interesting application for epoxy laminates is as a temporary patching material for metal and ceramic pipes, tanks, and vessels. The epoxies are of special interest here because of their rapid room-temperature curing, their excellent adhesion, and their high degree of chemical resistance. Patches are easily applied to damaged or corroded equipment without the need of any heat. This is a distinct advantage, particularly for field repairs where inflammable vapors are present.

Storage tanks containing solvents and acids at Diamond Alkali insecticide plant at Houston are sprayed with a three-coat protective finish based on Epon® resin. Shell photo.

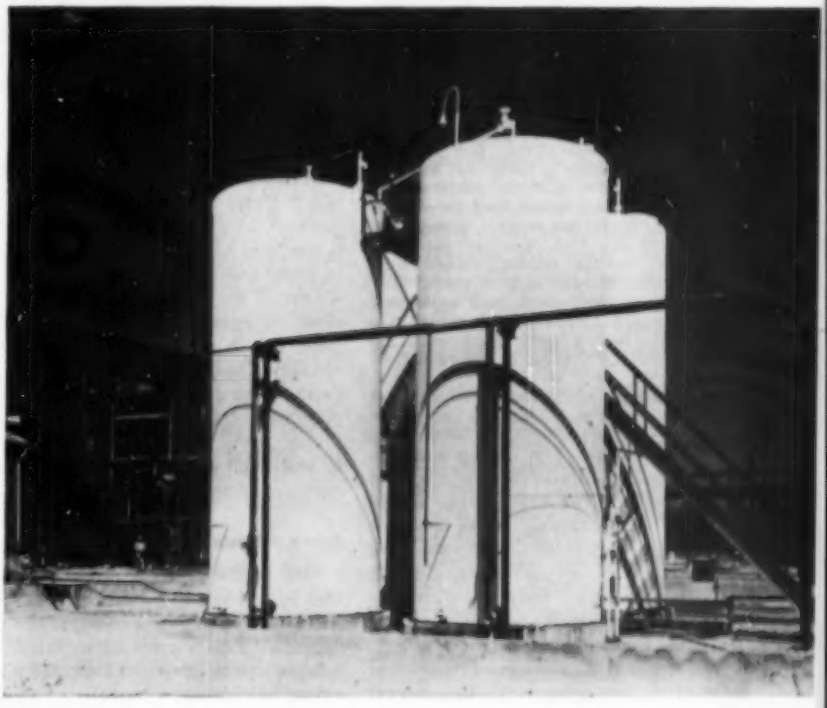


Table 3.—Strength Properties of Glass Reinforced Plastics (30% Glass)

	Sp. Gr.	Impact Strength (ft.lb./in.)	Stress at Fracture (1,000 lb./sq.in.)			Modulus of Elasticity (lb./sq.in. × 10⁶)		
			compression	flexure	tension	compression	flexure	tension
Melamine-glass	1.8	14	56	42	43	..	..	3
Allyl-glass	1.7	15	30	62	41	38	28	25
Polyester-glass	1.8	16	33	53	38	20	20	18
Silicone-glass	1.7	8	10	9	5	..	1	..
Phenolic-glass	1.6	7	18	23	23	..	15	20
Epoxy-glass	1.9	17	63	70	55	43	37	35
24 ST aluminum	2.7	22	64	64	44	..	10	..
Structural steel	7.8	42	60	60	60	..	29	..

These patches are applied to the cleaned surface by first brushing on a thick coat of liquid epoxy resin to which a low-temperature curing agent has been added. A piece of glass cloth cut so that it extends beyond the hole is then laid over the coated surface. The cloth is worked with a wooden paddle to impregnate the cloth with the resin. A second and third layer is then applied, and more if necessary, with the resin being brushed over each layer of glass cloth. The patch is finished by brushing a thick coat of resin over the final layer of cloth. After curing, the equipment can be returned to service. The U. S. Navy has written a specification around this type of epoxy patch for emergency damage control aboard ship. Qualifications require such a patch on a 2½-in. diam. pipe to withstand a pressure of 200 lb./sq.in. 1 hr. after application. On a flat plate such a patch must withstand a pressure of 2,000 lb./sq.in. before failure.

Epoxy Castings

Epoxy castings are usually made from the liquid resins. The curing agent is stirred into the resin before use, and the casting is cured either at room temperature or by baking in an oven at moderate temperatures. The properties which make the epoxies outstanding in the casting field are their low shrinkage during cure, simplicity in handling, high strength, good heat resistance, dimensional stability, and good electrical properties. At present the two largest uses for epoxy-casting formulations are as potting compounds for the electrical industry and as a die material for the tooling industry.

Tiny radar-type electronic sets are used in all of the guided missiles which are becoming increasingly important in national defense. These circuits must be potted to eliminate damage from mechanical and thermal shock as well as damage from water or vibration.

Epoxy casting resins are also being used to pot transformers and windings of electric motors for use in severe exposures. One such type of potted motor has also been used to make combination motor-pump and motor-compressor units. One of these units is made by inserting the pump package inside the motor stator and encapsulating the entire unit with epoxy resin. A half-horsepower unit made this way is only 6 in. in diam. and 6 in. long.

One of the most interesting applications of epoxy castings at present is their use in metal forming dies. The epoxies are ideally suited to this application since their low shrinkage provides accurate reproduction of the master forms. They also have good resistance to heat, high compressive strength, good adhesion, and are easily cured.

Epoxy Adhesives

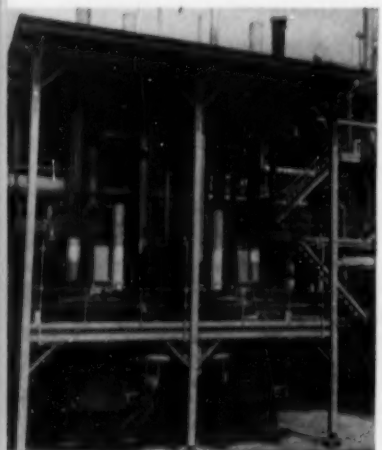
One of the inherent properties of all the epoxy resin formulations is their adhesion to many different types of surfaces. A wide variety of industrial adhesives can be prepared from the epoxy resins which show excellent bonding properties. In contrast to many organic adhesives, the epoxy resin adhesives require little or no pressure to bond two surfaces together. In addition, they are cured at moderate temperatures or even at room temperature. Although they are fluid, they contain no volatile solvents, thus eliminating the need for an evaporation period between application of the adhesive and assembly of the parts.

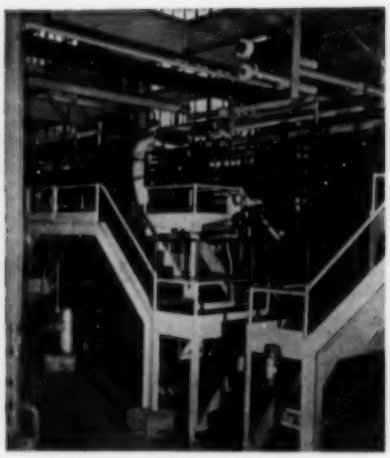
Epoxy adhesives have the ability to bond a wide number of dissimilar materials together. Wood, glass, steel, aluminum, plastic, ceramic, and rubber are easily bonded with these adhesives. Like the other epoxy polymers, they have excellent chemical resistance. Their high lap shear strengths, over 2,000 lb./sq.in., have created wide acceptance for these adhesives in the aircraft industry. Overall joint strengths of adhesive bonded sheet metal are not only higher than for riveted joints, but the bonded joints are also free of points of strain. Epoxy bonded joints also show more than twice the strength of soldered joints.

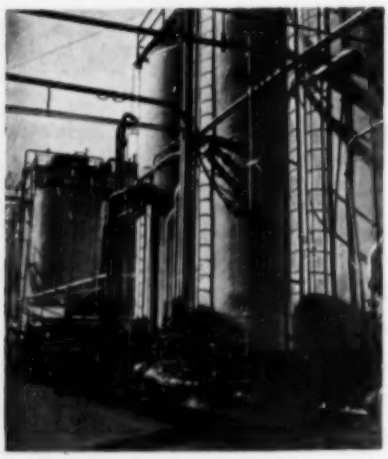
A recent development is the use of these adhesives in making rigid, high-strength, low-weight structural members for aircraft construction by bonding aluminum skins to a paper or aluminum honeycomb core about ½-in. thick. Their moderate curing conditions make the assembly of these members a simple operation.

A new type of epoxy adhesive of great promise has been developed in the form of a film rather than a paste. The epoxy resin is impregnated on a glass cloth carrier. For use, a piece of the adhesive film of suitable size is inserted between the two members to be bonded, and the bond is made by heating. This special type of adhesive has the ability to withstand temperatures up to 500° F. It is intended for use in supersonic aircraft and guided missiles where air friction generates temperature conditions of this magnitude.

Epoxy resins in industrial application | ***at Monsanto's John F. Queeny Plant, St. Louis, Mo. Photos are reproduced through the courtesy of Monsanto Chemical Co.***







Epoxy resins protect (1) an open chemical structure exposed to acid and weathering conditions, (2) an interior installation exposed to solvent conditions, and (3) exterior storage tanks exposed to general chemical and weathering conditions.

Heat Transfer and Flow Friction Characteristics of Porous Media

J. E. Coppage and A. L. London | Stanford University, Stanford, California.

A porous medium may be defined as an aggregation of solid bodies arranged so that the void spaces between the bodies are connected and will permit the through passage of a fluid. In this rather general definition a porous medium may be a single tube with fluid flowing through it; or a bank of parallel tubes with fluid flowing in a direction normal to the axis of the tubes; or a bed of spheres or gravel. As the flow characteristics of general three-dimensional flows, typified by the last example, appear to be quite different from those of one- or two-dimensional flows through regular passages, as in the first two examples, the term porous media will be used throughout this paper to refer only to those random aggregations of solids which result in three-dimensional flows with frequent expansions and contractions.

Among the important applications requiring a knowledge of, and a comprehensive information on, heat transfer, mass transfer, and flow friction characteristics of porous media are: (1) absorption and stripping columns, (2) catalyst beds, (3) periodic-flow heat exchangers, and (4) nuclear reactors.

The first two applications are well-known examples of the use of granular packings to obtain a large surface area in a small volume for continuous flow mass transfer and chemical reactor systems.

The third, namely the periodic-flow, regenerative heat exchanger is a device in which the energy transfer from hot to cold fluid is accomplished by a transfer from the hot fluid to a solid matrix followed by a later transfer to the cold fluid. Common examples of this type of exchanger are the Ljungstrom air preheater or blast furnace brick checkerwork air preheaters. The compactness of such exchangers can vary greatly with the use of different porous media; for example, wire screens having 300 mesh/in. provide about 11,400 sq.ft. of surface area/cu.ft., compared with 0.8 sq.ft./cu.ft. for brick checkerwork.

Nuclear reactors, the fourth application, may employ moderator and fuel elements in the form of porous media with the cooling fluid passing directly through them. This would mean more effective cooling, with a possible reduction in reactor bulk and therefore shielding volume.

Although some work has been done in this country and some in Great Britain, there remains a dearth of data in the literature, especially on the heat transfer characteristics. More recently, under the Office of Naval Research sponsorship at Stanford University, a body of data on packer screen matrices, and for one sphere bed, has been obtained (*1*), and the main purpose of this paper is to present these later results. More specifically, the objectives are (1) to present convective heat transfer and flow friction data for the flow of air through wire screen matrices and sphere matrices; (2) to summarize previous work in the field and to compare the previous results with the results of the present investigation; and (3) to propose a useful general correlation of the available heat transfer data.

Experimental Data

DESCRIPTION OF MATRICES

Matrix materials used in the investigation were woven wire screens, and spheres only. The reasons for this restriction are: (1) the geometries are completely known and controllable, so that results may have more general applicability; (2) wire screens permit a fairly wide variation of geometric parameters while providing the random, three-dimensional flow which is characteristic of porous media; (3) sphere bed geometry is at the other end of the porosity spectrum from wire screens, thus giving a broad range of porosity tested by one technique, and in addition, spheres are the "standard" used in flow friction correlations for granular materials; (4) wire screens are of direct interest in periodic-flow heat exchanger applications.

Test matrices were constructed, one from each of six different sizes of stainless steel wire screen and one from one size of lead shot. The photograph, Figure 1, indicates the type of wire screen matrix tested, along with the matrix-holding device. Details are given in Tables 1 through 4 (A.D.I.).

The screen matrices were all composed of 2.985-in. diam. circular sections of stainless steel wire screen contained in a balsa wood holder. For a given type of screen several matrices were tested, each having a different number of screens. The reason for this is to minimize the net experimental error arising from the effect of heat loss to the surroundings. In contrast to the conventional steady-state technique it is much more important to insure a small heat leak for the transient technique (*1*). One series of matrices was tested to obtain information on the effect of separating the screens (Table 3). The screens were separated 1/16 in. by gluing three short segments of 1/16-in. diam. brass rod around the periphery of each screen, and by stringing 1/16-in. "washers" made from 1/16-in. diam. brass tubing in the centers of the screens to keep the screens plane.

The sphere matrices were held in position by two 60 × 60 mesh, 0.011-in. wire diam. screens, which were in turn supported by two X-shaped braces made of ¼-in. wide strips of 0.015-in. steel shim stock, set edgewise to the flow.

EXPERIMENTAL METHOD AND EQUIPMENT

Briefly, the experimental method used in obtaining the heat transfer data is as follows: the matrix, initially at a uniform temperature, is heated by a fluid (air for these tests) which enters at a constant, higher temperature. The temperature-time history of the fluid leaving the matrix is recorded during this heating process. This heating curve is compared to the temperature-time curves from the Schumann analysis of heat transfer to an idealized porous medium (*2*), and in this manner the heat transfer unit conductance can be determined. In the present method the comparison between actual and analytically predicted curves is accomplished by matching only the maximum slopes. Other means of comparison are covered (*1*) and (*3*) and further discussion of this experimental technique is contained in (*5*, *7*, and *8*).

Fig. 1. Photograph of matrix-holding device and 5 × 5 mesh wire-screen matrix.

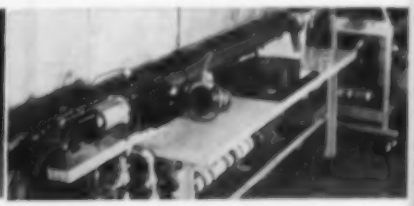


Fig. 3. Photograph of test apparatus.

J. E. Coppage is with the AiResearch Manufacturing Company, Los Angeles, California.

A. L. London is presently with the Reactor Engineering Division, Argonne National Laboratory, Lemont, Illinois.

Tables 1-4 are on file (Document 4782) with A.D.I. Auxiliary Publications Project, Library of Congress, Washington, D. C. These data are obtainable by remitting $1.25 for photoprints and $1.25 for microfilm.

The flow friction experimental method is the conventional steady-state isothermal flow procedure used by most investigators, in which the pressure drop is measured for essentially constant density air flow.

The experimental apparatus used in these tests (see Figures 2 and 3) consisted essentially of a rotameter type of air-flow measuring device, a flow-straightening section, an electric resistance heater, an air switch-box, the matrix and matrix-holding device, upstream and downstream thermopiles (eight junctions), and a temperature recorder. For the heat transfer runs air was by-passed through the switch-box while being heated; when the air and switch-box temperatures became stabilized at about 20° F. above room temperature, the air was switched to pass through the matrix, and the data were then recorded. Care was taken to insure uniformity of initial matrix temperature by a preliminary flow of unheated air at essentially room temperature. The matrix holder pictured in Figure 1 was made of balsa wood. This material has the requisite characteristics of both a low thermal conductivity and a low volumetric specific heat. A detailed consideration is given of the influence of heat leak on the test accuracy (*1*).

For the flow friction runs the air switch-box was replaced by a piezometer ring and pressure drop measurements were taken with inclined manometers during steady-state flow conditions.

Results

1. HEAT TRANSFER DATA

Heat transfer results are presented first in a semigeneralized form by a modified Stanton number times Prandtl number vs. Reynolds number plot. The modifications consist of somewhat different definitions for the mass velocity and characteristic dimension from what are usually employed. These quantities have been defined to represent certain average conditions within the complex flow passages of the matrix. The point of view adopted here is that the general porous medium must be viewed as an aggregation of flow passages rather than as an aggregation of solid bodies. The characteristic dimension is defined as the hydraulic diameter, D_h, where $D_h = 4r_h$

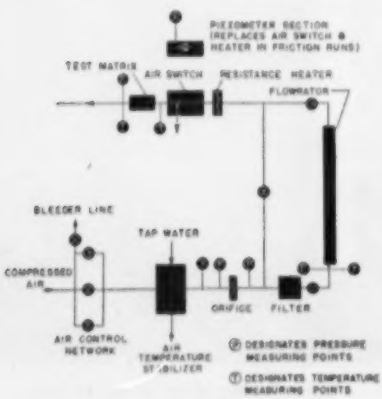


Fig. 2. Flow diagram.

and $$r_h = \frac{a}{\beta} \qquad (1)$$

in which

$$a = \frac{\text{total volume of connected void spaces}}{\text{total volume of matrix}} = \text{porosity}$$

$$\beta = \frac{\text{total surface area of connected voids}}{\text{total volume of matrix}} = \text{area density}$$

It can be readily shown that this definition coincides with the usual one when considering flow in cylindrical passages. For the average mass velocity definition an average free flow cross-sectional area, A_f, may be defined such that

$A_f L$ = volume of flow passages in matrix $= aA_t L$

Thus

$$A_f = aA_t \qquad (1a)$$

where A_t is the total frontal area of the matrix. The average mass velocity, G_t, is then defined by

$$G_t = \frac{w_f}{A_f} = \frac{w_f}{aA_t} = \frac{G}{a} \qquad (1b)$$

Similarly, the average flow velocity, V_t, is

$$V_t = \frac{G_t}{\rho} = \frac{G}{a\rho} = \frac{V}{a}$$

The data presentation is in the form

$$\left(\frac{h}{G_t c}\right)\frac{c\mu}{k} = \Phi\left(\frac{4r_h G_t}{\mu}\right) \qquad (2)$$

or

$$N_{St} N_{Pr} = \Phi(N_R) \qquad (2a)$$

for each type of screen tested.

The above representation is reasonably complete for granular beds or porous solids all of approximately the same porosity, but for wire screen matrices a new parameter and further modification of G_t and D_h are necessary. As the screens may be separated from each other, a longitudinal pitch ratio must be introduced. The following definition is used.

$$p_L = \frac{\text{distance between screen center-planes}}{\text{screen thickness}} = \frac{L - \delta'}{(n-1)\delta'} \qquad (3)$$

where δ' is the thickness of one screen ($\delta' \approx 2D_w$). In order to allow the effects of screen separation to be reflected *only* by p_L, it is necessary to change the definition of a and β so that they will not vary when the screens are separated. By introducing a' = porosity of a single screen and β' = surface area per unit volume for a single screen where volume measurements are made between the bounding planes of the screen, the effects of screen separation are eliminated, and further, these quantities become identical with a and β for a perfectly packed matrix (i.e., $p_L = 1$). Therefore,

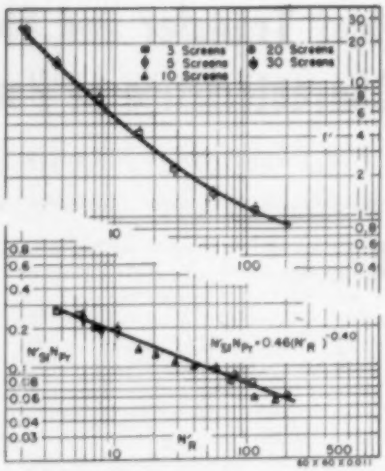


Fig. 4. $N_{ST}'N_{PR}$ and f' vs. N_R' for the 60 × 60 mesh—0.011-in. wire diam. screen matrices, $a' = 0.602$.

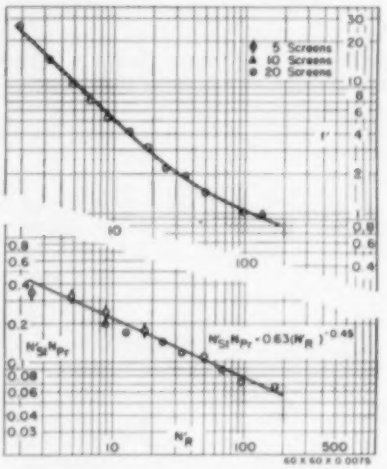


Fig. 5. $N_{ST}'N_{PR}$ and f' vs. N_R' for the 60 × 60 mesh—0.0075-in. wire diam. screen matrices, $a' = 0.675$.

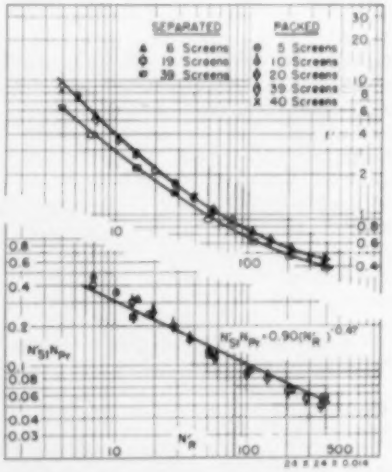


Fig. 6. $N_{ST}'N_{PR}$ and f' vs. N_R' for the 24 × 24 mesh—0.014-in. wire diam. screen matrices, $a' = 0.725$.

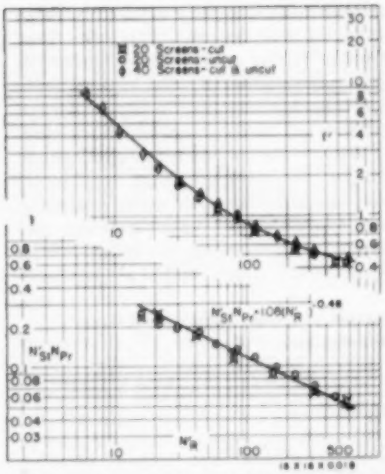


Fig. 7. $N_{St}'N_{Pr}$ and f' vs. N_R' for the 16 × 16 mesh—0.018-in. wire diam. screen matrices, $a' = 0.766$.

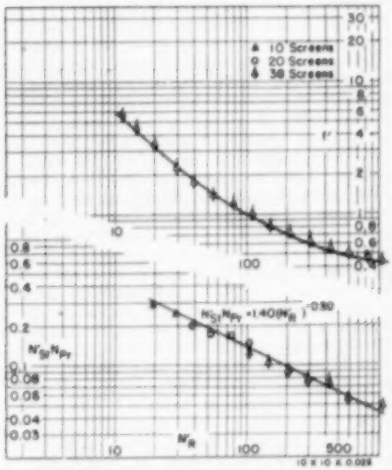


Fig. 8. $N_{St}'N_{Pr}$ and f' vs. N_R' for the 10 × 10 mesh—0.025-in. wire diam. screen matrices, $a' = 0.817$.

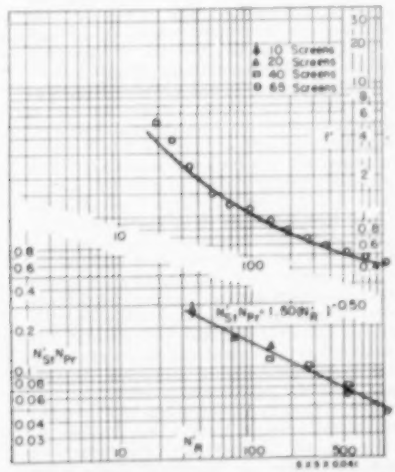


Fig. 9. $N_{St}'N_{Pr}$ and f' vs. N_R' for the 5 × 5 mesh—0.041-in. wire diam. screen matrices, $a' = 0.832$.

$$\left.\begin{aligned} D_h' &= 4r_h' = 4(a'/\beta') \\ A_f' &= a'A_s \\ G_s' &= w_f/A_f' = G/a' \\ V_s' &= G_s'/\rho \quad V/a' \end{aligned}\right\} \qquad (4)$$

and the data for wire screens will be represented by

$$\left(\frac{h}{G_s'c}\right)\left(\frac{c\mu}{k}\right)^{\left(=\Phi\right)}\left(\frac{4r_h'G_s'}{\mu}, \; f_L\right) \qquad (5)$$

or

$$N_{St}'N_{Pr} = \Phi(N_R', f_L) \qquad (5a)$$

Heat transfer data obtained for the wire screen matrices are shown in Figures 4 through 9 (lower half). It will be noted that the data are well represented by straight lines on the log-log plots for the range of Reynolds numbers covered. It seems quite probable, however, that these straight lines are merely approximations to segments of curved lines, the small curvature having been masked by the experimental uncertainty of the present work. This uncertainty interval is estimated to be ±15% for the heat transfer data, due primarily to the difficulties inherent in the experimental method.*

The reason that curvature is to be expected is that the present data lie in the transition Reynolds number range, as demonstrated by the flow behavior, and nearly all heat transfer data for all types of geometries exhibit some degree of curvature in this range. It should be noted that early transition is quite characteristic of bluff bodies or irregular flow passages, in which flow separation and vortices appear at low Reynolds numbers. Thus the straight line representation should not be extrapolated beyond $5 < N_R < 1{,}000$, and this points out the need for data covering a wider N_R range.

A general, empirical correlation of the wire screen results was discovered. It was found that both the slope and position of the straight line, fitted to the individual sets of data, definitely tended to increase with an increase in the screen porosity a'. Note that each of Figures 4 through 9 represents one a'. This led to the following relation:

$$N_{St}'N_{Pr} = \phi(a') \times N_R'^{-m} \qquad (6)$$

where $\phi(a')$ and m are plotted in Figure 11 as functions of a'. The coefficient $\phi(a')$ defines the position, and the exponent m the slope of the straight lines on the log-log plots, Figures 4 to 9. This type of correlation was found to be capable of representing virtually all data points to within ±20%; the dotted curves in Figure 11 indicate ±20% deviation from the recommended correlation line (solid curve). The vertical lines terminated by short horizontal lines represent the spread of the data about the straight lines drawn in Figures 4 through 9.

Some tests were performed to establish the influence of screen separation. The 24 × 24 mesh, 0.014-in. diam. wire screens were tested both in the packed condition (f_L about 1.1) and with a separation giving a f_L of about 3.2 (see Figure 6). No change in heat transfer characteristics could be detected which exceeded the experimental uncertainty. This result is supported by additional data (5). Thus, for the heat transfer data, f_L is evidently not a significant parameter. This conclusion would not have been evident without the use of a' and β' as correlating factors in place of a and β.

The experimental data for the sphere matrices are presented in Figure 10, where $N_{St}N_{Pr}$ is plotted against N_R. The reported Reynolds number range was less than for the screen tests because of limitations imposed by the calculated experimental uncertainties. However, it is felt that the 20-fold range

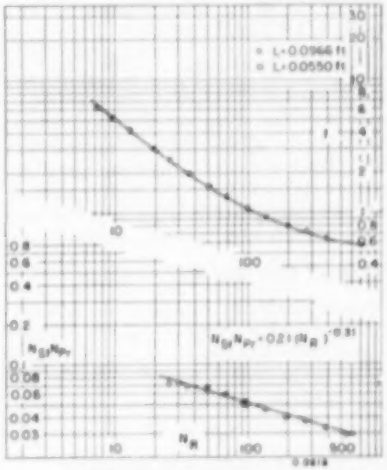


Fig. 10. $N_{St}N_{Pr}$ and f vs. N_R for the 0.0818-in. diam. sphere matrices, $a = 0.385 - 0.390$.

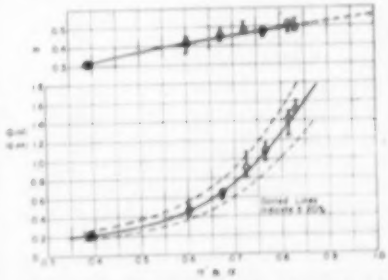


Fig. 11. Correlation of heat transfer data of present investigation—exponent and coefficient for Equation (6)—m, $\phi(a')$ and $\phi(a)$ vs. a' and a.

* The straight lines shown in Figures 4-9 do not represent the best fit for each set of data because they are derived from the more general correlation for all the matrices, including sphere beds, which will be described later.

covered is enough to allow some general conclusions.

A point of interest is how the sphere data compare with the general correlation for screens in Figure 11. A straight line through the data gives a best fit $m = 0.31$ and a best fit $\phi(a) = 0.21$. These points are plotted in Figure 11 for $a = 0.39$. It is quite evident that the sphere data point on this curve is definitely within reach of reasonable extrapolations of the m and $\phi(a)$ functions indicated for screens. These extrapolations have been drawn in, and data from previous investigations will be introduced later to provide additional support for this general correlation.

INFLUENCE OF PRANDTL NUMBER

For all the present results $N_{Pr} = 0.71$ and $N_{Pr}{}^{\frac{2}{3}} = 0.796$. A $N_{St}{}'N_{Pr}{}^{\frac{2}{3}}$ correlation is employed instead of $N_{St}{}'N_{Pr}{}^{\frac{2}{3}}$, because it is believed that the flow is essentially of a laminar nature, and an exponent of unity, as for laminar flow in long ducts, was deemed most appropriate.

One may well argue that a two-thirds exponent is more appropriate and, until this question is settled, it is left to the user of these results to employ his own judgment. It is a simple matter to convert Equation (6) to an $N_{Pr}{}^{\frac{2}{3}}$ form by multiplying $\phi(a')$ from Figure 11 by $0.796/0.71 = 1.12$.

2. FLOW FRICTION DATA

The flow friction data are presented in a modified Fanning friction factor vs. Reynolds number type of representation. By the use of reasoning parallel to that presented for the heat transfer consideration, suitable definitions for the friction factor and Reynolds number are:

GRANULAR BEDS AND POROUS SOLIDS

$$\left.\begin{aligned} f &= \frac{\Delta P/\rho}{(L/r_h)(V_s{}^2/2g_c)} \\ &\quad \text{(definition of } f\text{)} \\ N_{Re} &= \frac{(4r_hG_s/\mu)}{\text{(definition of } N_{Re}\text{)}} \\ f &= \phi(N_{Re}) \end{aligned}\right\} \qquad (7)$$

WIRE SCREENS, PACKED AND SEPARATED

$$\left.\begin{aligned} f' &= \frac{\Delta P/\rho}{(n\delta'/r_h')(V_s{}^2/2g_c)} \\ &\quad \text{(definition of } f'\text{)} \\ N_{Re}' &= \frac{(4r_h'G_s'/\mu)}{\text{(definition of } N_{Re}'\text{)}} \\ f' &= \phi(N_{Re}', p_L) \end{aligned}\right\} \qquad (8)$$

Experimental results for the flow friction behavior of wire screen matrices are shown in Figures 4 through 9 (upper half). The expected uncertainty interval is ±5%. These curves, starting just within the laminar flow region and extending well into the transition region, clearly reveal the transitional character of the flow, nearly to a fully developed inertial flow condition.

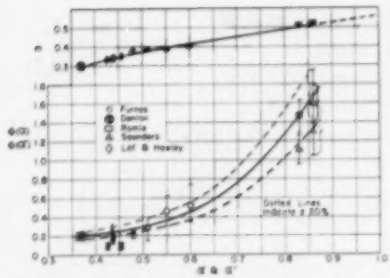


Fig. 12. Correlation of heat transfer data from other investigations. Heavy lines are from Fig. 11.

Attempts to obtain a more general correlation for flow friction data were not successful. The only statement of a general nature which can be made is that all the data for the various matrices lie within ±25% of a median curve for the range of Reynolds numbers investigated (Figure 13).

Contrary to the heat transfer behavior, the effects of screen separation on flow friction are quite marked. Figure 6 reveals that for $a' = 0.725$, a change of p_L from 1.1 to 3.2 results in a decrease in pressure drop on the average of 25%. The same type of behavior has been noted in low Reynolds number flow over tube banks (6). For higher Reynolds numbers the advantage decreases, and screen separation may even become a disadvantage, as in tube banks.

The flow friction characteristics of the sphere matrices are presented in Figure 10 (upper half). As data on sphere bed flow friction behavior have been established by many investigators, this inclusion here gives no really new information, but it supports the reliability of the present test procedure and instrumentation.

3. VARIATION OF FLUID PROPERTIES IN THE BOUNDARY LAYER

As the maximum temperature difference for heat transfer employed in these tests did not exceed 20° F., the heat transfer results reported here do not involve the question of what kind of average temperature to use in the evaluation of "film average" properties. Extension of these data to technical applications will of course require some decision on this currently debatable point, especially where large temperature differences and strongly temperature-dependent fluid properties, N_{Pr}, μ, c, and ρ, are involved.

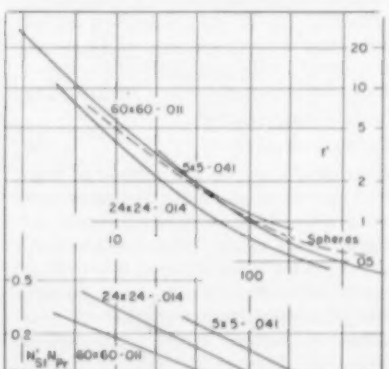


Fig. 13. Extremes of heat transfer and flow friction behavior of wire-screen matrices, and relative position of sphere data.

Comparison with Data of Previous Investigators

1. HEAT TRANSFER DATA—WIRE SCREEN MATRICES

The inherent experimental difficulties of obtaining reliable heat transfer data for porous media have retarded the accumulation of results. Only three previous investigations have been made which included tests of wire screen matrices: that of Romie and associates (5), that of Saunders and Smoleniec (8), and that of Johnson (9).

Romie, using essentially the same experimental method as employed in the present work and covering about the same Reynolds number range, tested two screen matrices, in which the screens were separated 1/32 in. In order to compare these data with the present results, a mean straight line was drawn through the points for each matrix. Due to scatter, more than one interpretation was possible; the one selected was the best straight line having a slope taken from the m vs. a' curve in Figure 11. It should be pointed out that in order to convert Romie's data to the $N_{St}{}'N_{Pr}$ vs. $N_{Re}{}'$ type of representation used in the present work, it was necessary to assume a value of δ', the screen thickness. The best estimate that can be made is that $\delta' = 2D_w$, even though this assumption may be in error by as much as 10%, as can be seen by examining Table 1. The estimated uncertainty is only about 5%, however, with the introduction of an expected uncertainty of 5% in both $N_{St}{}'$ and $N_{Re}{}'$, attributable to the error in δ' alone.

Results of this conversion are shown in Figure 12, where the general correlation of the present data from Figure 11 and the results of some previous investigations are presented. Romie's data comprise two points — for porosities $a' = 0.83$ and $a' = 0.86$. The points are in excellent agreement with the present data.

The conclusion of the present investigation, namely that screen separation has a negligible effect on heat transfer behavior is confirmed when one recalls that Romie's matrices had the screens separated. The spread of Romie's data is indicated, as before, by the vertical lines through the points, terminated by short horizontal lines.

Saunders and Smoleniec (8), using very nearly the same experimental method as in the present work and covering about the same Reynolds number range, tested three wire screen matrices, all closely packed. The data were converted to the method of presentation used here in the same way that Romie's data were converted. In this case, however, information given in (8) indicated that the assumption of $\delta' = 2D_w$ was quite correct for the screens tested.

Results of Saunders and Smoleniec are shown by points in Figure 12, there being two matrices having $a' = 0.86$ and one having $a' = 0.83$. One of the $a' = 0.86$ matrices falls definitely into the pattern

indicated by the present (and Romie's) work; the other two matrices are about 20% below this pattern. The test results for at least one of these low points are open to question—the two $a' = 0.86$ matrices are geometrically identical and, therefore, the results would be expected to lie quite close together. It is possible that the difference is due to experimental errors, but the spread would indicate an uncertainty of about ±30%. It is concluded that no satisfactory explanation of this difference can be given on the basis of the information available in (*8*) and this same statement applies also to the $a' = 0.83$ matrix.

Johnson (*9*) tested three types of screen matrices by the same method and in the same Reynolds number range as employed by the other investigators. These data are not included here because it is believed that the heat losses to the boundaries were excessive and that the upstream temperature was not regulated closely enough. Furthermore, a large discrepancy between the results for two geometrically similar matrices has not been accounted for. The data lie 35 to 50% below the present results, though it should be noted that these data at least follow roughly the same increasing trend of $\phi(a')$ as indicated by the correlation curve in Figure 12.

2. HEAT TRANSFER DATA—SPHERES AND GRANULAR MATERIALS

Several investigators have obtained data on the heat transfer behavior of matrices composed of spheres and granular materials, but few have attempted to cover any appreciable range of Reynolds numbers for a given matrix. For beds of spheres Denton (*10*) used a steady-state technique to obtain data for Reynolds numbers from 500 to 50,000. The results were found to be well represented by

$$\frac{h}{Gc} = 0.72\left(\frac{GD_s}{\mu}\right)^{-0.59} \qquad (9)$$

The fluid used was air having a Prandtl number of 0.73, and since the porosity was $a = 0.37$, Equation [9] becomes

$$N_{St}N_{Pr} = 0.20(N_R)^{-0.59} \qquad (10)$$

for $500 < N_R < 53{,}000$. This result is to be compared to the present results for a bed of spheres having $a = 0.39$, for which

$$N_{St}N_{Pr} = 0.21(N_R)^{-0.59} \qquad (11)$$

for $25 < N_R < 550$, see Figure 10. The agreement is excellent, and with allowance for the slight difference in porosity, the present results form a continuation of Denton's results to lower Reynolds numbers, thus evidently supporting the linear log-log relationship for spheres over a 2,000 fold N_R range. Possibly this result may be interpreted as supporting a similar extrapolation for screen matrices to higher Reynolds numbers. Such an extrapolation would probably be conservative. The magnitudes of $\phi(a)$ and m from Equation (*10*) have been included in Figure 12.

Some additional support for these results for spheres is given by the work of Saunders and Ford (*11*). They obtained data for sphere beds of $a = 0.38$ at only two Reynolds numbers, but these two points straddle the present data and fall within 10% of the straight line representing the data.

Other tests on sphere matrices have been reported and are available in a good review by Denton (*10*). For various reasons results of those investigations are not considered representative of infinite matrices or are deemed to be of insufficient accuracy, so that they were omitted from the present comparison.

In summarizing on spheres, the excellent agreement between the results of Denton, Saunders, and the present work indicates that the heat transfer behavior of sphere matrices is fairly well established over the range of Reynolds numbers from 25 to 50,000. It is therefore recommended that Equation (6) (with the primes removed) and Figure 12 be used for predicting sphere matrix heat transfer performance.

The information regarding heat transfer in matrices composed of granular materials other than spheres is much less complete. Furnas (*12*) used the transient technique in a large number of experiments on beds of materials such as broken pieces of limestone, iron ore, and coke. However, though the number of different matrices and porosities tested was large, the Reynolds number range in each case was very small. In addition, the wall effects in these experiments were rather large; that is, the ratio of matrix container diameter to the average particle diameter was not large enough to assure an approach to infinite matrix behavior, and the heat losses to the walls were sufficient to cause considerable error in the heat transfer coefficients. Nevertheless, as these data represent the majority of the work done on granular materials, it is desirable to consider these results in the present study.

By making some reasonable assumptions, it was possible to convert Furnas' data to the present representation. The result was a rather wide scatter of points, so that in order to include the data on Figure 12 the log-log slope m was taken from the curve in Figure 11 as a function of the various porosities, and the best position, $\phi(a)$, was then determined. Results are shown in Figure 12 for $a = 0.48$, 0.51, 0.55, and 0.60, in which the porosities are *average* values, each representing a range of porosities within about ±5% of the average. Each point represents data for a number of different types of matrices of about the same porosity.

The results are quite encouraging. Three of the points on Figure 12 lie within 20% of the correlation line, and the other is within 25%. It can be seen that the bulk of the data lies within the ±20% lines, and furthermore the trend as a function of porosity agrees with the suggested correlation.

One other group of experiments dealing with granular materials has been reported. Löf and Hawley (*7*) used the transient technique to examine four sizes of gravel within the same Reynolds number range as in the present work. In order to convert their data for comparison with the other results, it was assumed that the surface area of the gravel particle was 15% greater than the surface area of the sphere having the same volume. Information (*7*) seemed to indicate that the gravels were reasonably rounded, but the 15% figure may be somewhat low.

Results of the conversion are shown on Figure 12 for $a = 0.426$, 0.434, 0.436, 0.454. Two of the $\phi(a)$ points are only 30% below the correlation line, but the other two are 60% below. Note that all points are on the low side. At least part of this difference may be explained by heat losses to the container walls, and to other thermal capacitances in the test section. Examination of information in (*7*) indicates that as much as 20% heat loss may have existed in some cases. Also, the fact that the number of data points taken for each matrix was rather small (from three to eight), coupled with the inevitable experimental uncertainties, could account for some of the remaining discrepancies, though, of course, no definite conclusions can be drawn.

In view of the foregoing it is seen that there is a fair possibility that porosity alone may be capable of correlating porous media heat transfer data. It is clear that a complete specification of geometry requires additional parameters, and it is quite possible that some of the discrepancies with granular materials may be accounted for in this fashion. However, it is evident that porosity is one of the dominant parameters in this scheme, and it remains for accurate experiments with granular materials to establish the agreement or disagreement with this simple correlation. Present results are at least not discouraging.

Some experimental heat transfer data for sintered metals have been reported (*13*), virtually the only data for sintered metals. These could not be included here, as it was not possible to estimate a magnitude for the area density, β.

3. FLOW FRICTION DATA—WIRE SCREEN MATRICES

Flow friction data for porous media are relatively plentiful due mainly to the simple experimental technique requirements. There is much information on beds of granular materials and sphere beds, etc., however, data for wire screen matrices are still somewhat limited. Only Romie (*5*), Saunders and Smoleniec (*8*), Johnson (*9*), and Locke [some unpublished data obtained after the publication of (*3*)] have obtained screen data.

Saunders and Smoleniec did not actually publish their work,, but the authors stated in (*8*) that their results agreed well with the work of Rose (*15*).

Romie's work could not be converted for comparison with the present results because the screen thickness, δ', was not known accurately. Though the approximation of $\delta' = 2D_w$ is adequate for converting the heat transfer data, the definition of f' is such that an uncertainty of ±15% could be introduced by this approximation, and this could lead to false conclusions. However,

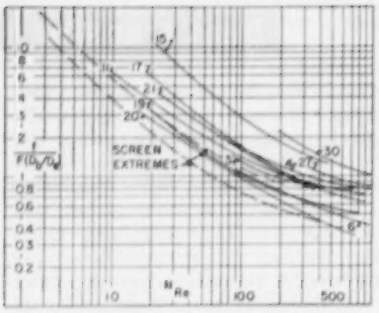


Fig. 14. $\frac{f}{F(D_b/D_e)}$ vs. N_R for data of (15) and comparison with extremes of wire-screen behavior.

Curve number	Bed material
3	solid cylinders
4	solid cylinders
6	solid cylinders
11	hollow cylinders
15	hollow cylinders
17	Lessing rings
19	rivets
20	nails
21	nails
27	egg insulators
30	standoff insulators

the trends of Romie's data agreed well with the present results. His data on separation of screens indicate the same magnitude of reduction of pressure drop for the same amount of separation. Romie went somewhat further into the matter of screen separation, and his results indicate that an optimum spacing may exist, between $p_L = 3$ and $p_L = 6$. However, his tests used small numbers of screens in some cases so that this point requires additional tests for confirmation.

Johnson (*9*) obtained data which had an unusually large scatter for pressure drop tests, about ±10-15% (greater for one matrix). The data fell in the same range as the present results, but in view of the scatter it was not felt desirable to reproduce them here.

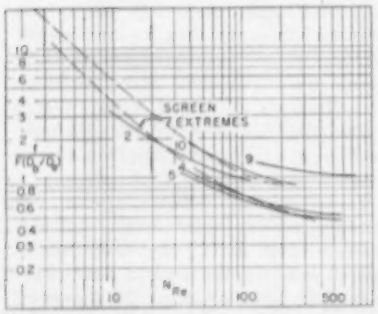


Fig. 15. $\frac{f}{F(D_b/D_e)}$ vs. N_R from data of (20), and comparison with extremes of wire-screen behavior.

curve number	bed material
2	solid cylinders
4	tablets
5	broken coke
9	broken coke
10	broken coke

4. FLOW FRICTION DATA—SPHERES AND GRANULAR MATERIALS

Flow friction data for matrices composed of spheres and granular materials are quite abundant. Rose (*14*) gives an excellent summary of work done in this field. Other important work has been done by Taliaferro (*16*), Fair and Hatch (*17*), Hatch (*18*), and Franzini (*19*). The major difficulty is that the geometries are not described sufficiently to permit conversion to the present basis in most cases.

More recently Rose and Rizk (*15*) have presented a study in which a large number of matrices of *known* geometry were tested with allowance made for the conversion of their results to the present basis. These are shown in Figure 14, in which are plotted curves of $f/F(D_b/D_e)$ vs. N_R for each matrix. The factor $F(D_b/D_e)$ accounts for wall effects, which were significant in some of their matrices, and was taken directly from (*15*). It is to be noted that the same factor is essentially unity for the wire screen matrix and sphere bed tests reported here. Results in this form are directly comparable to the present results for screen matrices, and the two extreme curves for screens are shown as dotted lines in Figure 14 for comparison. The numbers on the Rose and Rizk results refer to the matrices so designated in (*15*).

The variety of matrices shown in Figure 14 is great, ranging from nails to hollow cylinders to Lessing rings. In view of this factor the maximum spread of ±100% is not unexpected. This spread is far too wide to be properly termed a useful correlation, but it is highly probable that the flow friction data for the vast majority of porous media will be found somewhere within this band. It is interesting to note that Rose and Rizk, using slightly different definitions for mass velocity and characteristic diameter, proposed a correlation of their data in which the maximum spread was also about the same, even after they applied an empirical geometrical correction factor.

It is to be noted in Figure 14 that nearly all the data lying on the high side of the spread is for matrices composed of bodies which have holes through them, such as hollow cylinders, Lessing rings, egg insulators, and standoff insulators. If these matrices are excluded, the band spread for the remaining matrices is about ±35% over most of the N_R range, a somewhat greater maximum spread than for the screens. One possible explanation of the tendency towards higher friction factors for bodies with holes in them is that the holes comprise a large void space which is generally not as accessible to the flowing fluid as the void spaces between the bodies. From the definition, f is proportional to $(a)^3$. Thus, an incorrectly high effective porosity would result in an incorrectly higher f. Just what the correct porosity should be is difficult to say. The best course at the moment seems to be to treat solid bodies with holes as separate classification, each class with its own correlation.

The only other available data for granular materials which will admit of conversion to the present basis are Morcom's results (*20*). Enough information was given so that the surface areas, β, could be fairly well estimated, and the results are shown in Figure 15. The matrices were composed of cylinders, approximate spheres, tablets, and broken coke. Also shown are the present screen results. The maximum spread of Morcom's data is about ±40%, only a little larger than Rose and Rizk's solid body results. The difference is due principally to the broken coke data (Nos. 9 and 10 in Figure 15), the configuration for which the surface area parameter, β, is least certain. Finally, it should be mentioned that there exist some test results for sintered metals, though for reasons previously discussed they are not reproduced here. The reader is referred to a discussion by Grootenhuis (*13*) and to a paper by Green and Duwez (*21*) for data in this field.

Conclusions

1. Convective heat transfer and flow friction data have been obtained for matrices composed of woven wire screens and spheres in the Reynolds number range from 5 to 1,000. Data for closely packed screens cover a range of porosities from 0.60-0.83; data were also obtained for one separated screen matrix. The data for spheres were obtained for one randomly packed condition, $a = 0.39$.

2. Previous heat transfer data are limited, but agreement with present results was generally found within the expected experimental uncertainty limits. Previous flow friction data are plentiful, but inadequate geometric descriptions reduced greatly the amount of information which could be compared directly with the present results. Excellent agreement between present and previous results was found for screens and spheres. Results for granular media fall in the same region occupied by screen matrices.

3. An empirical correlation is presented for the heat transfer behavior of porous media based on the screen and sphere matrices behavior. This correlation indicates that the heat transfer behavior is strongly influenced by porosity. Additional data on granular media are needed to establish the correlation more firmly for application to commercial packings.

4. No satisfactory correlation for flow friction behavior of porous media was found. Data for packed screens and a wide variety of granular media fell into a definite range, but the spread is too large to be termed a correlation. The spreads could be materially reduced by dividing the granular media into matrices composed of solid bodies and matrices of bodies with holes through them.

Acknowledgment

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The authors are greatly appreciative of the contributions of Locke and of the support of the sponsoring agencies which made this investigation possible.

Notation

A = heat transfer area, sq.ft.

A_f = matrix free flow area, $A_f = aA_t$, sq.ft.

A_f' = free flow area of a single screen or of a perfectly packed screen matrix, $A_f' = a'A_t$, sq.ft.

A_t = matrix frontal area, sq.ft.

c = fluid specific heat at constant pressure, B.t.u./(lb.)(° F.)

D = diameter, ft.

D_b = bed diameter, or matrix diameter, ft.

D_e = equivalent sphere diameter, D_e = 6 × volume of particle/surface area of particle, ft.

D_h = hydraulic diameter, $D_h = 4r_h$, ft.

D_h' = hydraulic diameter of single screen or of a perfectly packed screen matrix, $D_h' = 4r_h'$, ft.

D_s = sphere diameter, ft., in.

D_w = wire diameter, ft., in.

G = mass velocity, lb./(hr.)(sq.ft.)

G_t = mass velocity based on matrix free flow area, $G_t = w_f/A_f$, lb./(hr.)(sq. ft.)

G_t' = mass velocity based on free flow area of a single screen or a perfectly packed screen matrix, $G_t' = w_f/A_f'$, lb./(hr.)(sq.ft.)

g_c = reciprocal of the proportionality factor in Newton's second law, g_c = 32.2 [(lb. mass)/(lb. force)](ft.)/(sec.)(sec.)

h = unit conductance for thermal convection, B.t.u./(hr.)(sq.ft.)(° F.)

k = fluid thermal conductivity, B.t.u./(hr.)(sq.ft.)(° F./ft.)

L = flow length of matrix, ft.

m = slope of log-log plot of $N_{St}N_{Pr}$ vs. N_R or $N_{St}'N_{Pr}$ vs. N_R', a function of porosity a or a'

n = number of screens in matrix

P = pressure, lb./sq.ft., in water

ΔP = pressure difference, lb./sq.ft., in water

r_h = hydraulic radius, $r_h = a/\beta$, ft.

r_h' = hydraulic radius of a single screen or of a perfectly packed screen matrix, $r_h' = a'/\beta'$, ft.

T = temperature, ° F.

V = velocity of fluid based on frontal area, ft./sec.

V_t = velocity of fluid based on free flow area, ft./sec.

V_t' = velocity of fluid based on free flow area of a single screen or of a perfectly packed screen matrix, ft./sec.

w_f = mass flow rate of fluid, lb./hr.

W_s = mass of solids in matrix, lb.

Greek Letters

a = porosity, the volume of voids/total matrix volume, nondimensional

a' = porosity of a single screen or of a perfectly packed screen matrix, nondimensional

β = heat transfer area per unit volume of matrix, ft.$^{-1}$

β' = heat transfer area per unit volume of a single screen or of a perfectly packed screen matrix, ft.$^{-1}$

δ' = thickness of a single screen, ft., in.

μ = viscosity, lb./(hr.)(ft.)

ρ = mass density, lb./cu.ft.

$\Phi(\ )$ = denotes a function of $(\ )$

$\phi(a')$ = the coefficient in Equation (6)

Dimensional Groupings

f = Fanning friction factor,

$$f = \frac{\Delta P/\rho}{(L/r_h)(V_t^2/2g_c)}$$

f' = friction factor used for screen matrices,

$$f' = \frac{\Delta P/\rho}{(n\delta'/r_h')(V_t^2/2g_c)}$$

N_{Pr} = Prandtl number, $N_{Pr} = c\mu/k$

N_R = Reynolds number, $N_R = 4r_hG_t'/\mu$

N_R' = Reynolds number employed for screens, $N_R' = 4r_h'G_t'/\mu$

N_{St} = Stanton number, $N_{St} = h/(G_tc)$

N_{St}' = Stanton number employed for screen matrices, $N_{St}' = h/(G_tc)$

p_L = longitudinal pitch ratio of screens,

$$p_L = \frac{L - \delta'}{(n-1)\delta'}$$

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PART II

The Use of Frequency Response Analysis in Chemical Engineering Process Control

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How frequency response characterization provides a simple means of determining requirements for controlling processes automatically has been shown (*2*). This article, a simple quantitative treatment of process control, identifies the bases for frequency response analysis, indicates how real processes may be represented and how effective control systems can be devised from such representation.

Signal Flow Diagram

In a control loop each element is important to the over-all performance of the system. This is more clearly apparent in a block diagram than in a conventional process flow diagram since each element appears as a block which is not related to the size of equipment.

The block diagram is a *signal flow diagram* in that it shows the flow of signals around the control loop. In its most primitive and complete form it identifies not only all flows and combinations of signals but also the mathematical functions relating each output and input. By the revealing of missing information and weak process designs it provides a powerful starting point for control studies (*1*).

Fortunately only a few basic, block types are needed to represent most process control systems. The processes can be represented by appropriate combinations of amplifiers, time lags, and time delays, and the controllers can be represented by amplifiers, differentiators, and integrators. Summing elements, multipliers, and dividers also may be necessary.

For example, the simple heat transfer system of Figure 1 can be represented by the block diagram of Figure 2. The controller is a summer and amplifier; the control valve is an amplifier and time lag; the jacketed kettle is a time lag; there is a time delay between the kettle and the temperature sensing element; and the thermometer element itself is another time lag. These various components will now be considered in detail.

SUMMER

One of the simplest elements in a control loop is the summer or adder, which adds or subtracts two input signals.

A typical and important summing element is the system of levers or other device which computes the deviation by subtracting the feedback measure of the process variable from the command signal to the controller. In Figure 2 the summer is shown in the controller as a circle with the letter sigma (Σ) in it.

AMPLIFIER

Another simple element is the amplifier, which multiplies the input signal by a constant.

It may either magnify or diminish the signal, and frequently it merely changes the dimensions of the signal. For example, in the case of the control valve in Figure 2 the output air pressure from the controller must be converted ultimately to a potential temperature in the kettle. Amplifiers are shown as blocks with the constant inside. Their outputs are given by the product of the constants and the inputs. Thus the controller output for proportional control is

$$\theta_o - \theta_{os} = K_p(\theta_c - \theta_s) \qquad (1)$$

TIME LAG

A time-lag element has the characteristics of resisting the flow of a quantity and of storing that quantity.

The thermometer in the outlet stream from the kettle is a good example of a first-order time lag. It can store thermal energy and the fluid film surrounding its sensing bulb resists heat flow. Quantitatively, its response to fluid temperatures is given by equating the heat balance and rate equations

$$W_b C_{pb} \frac{d\theta_b}{dt} = U_b A_b(\theta_a - \theta_b) \qquad (2)$$

This equation can be written in operational form as

$$\frac{\theta_b(s)}{\theta_a(s)} = \frac{1}{1 + T_b s} \qquad (3)$$

Systems which obey Equation (3) are sometimes called first-order transfer stages or first-order RC (resistance-capacitance) stages, the latter name resulting from the fact that the time constant of the stage is the product of a resistance term, $1/U_b A_b$, and a capacitance term, $W_b C_{pb}$. Since the right-hand part of the equation determines what happens to signals being transferred through the stage, it is frequently called the transfer function of the stage.

The Laplace transformation, which in fact is what converted Equation (*2*) into Equation (3), is a convenient tool for solving linear differential equations. However, for the purposes of this exposition it is only necessary to regard the Laplacian operator s as being an algebraic quantity which can be substituted for d/dt. In frequency response analysis the characteristics being sought are those which relate output and input when the input is a steady-state sine wave. This input condition is often called sinusoidal forcing.

When a time lag or any other element is forced sinusoidally

$$s = j\omega \qquad (4)$$

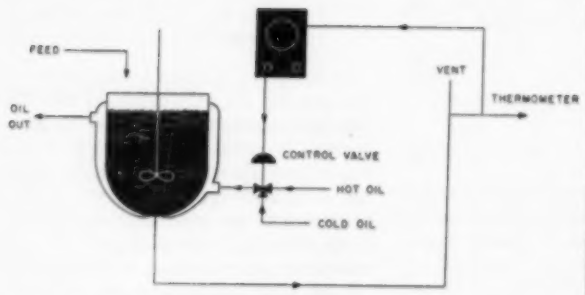

Fig. 1. Controlled heat transfer system.

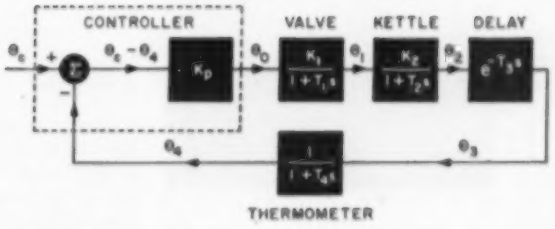

Fig. 2. Block diagram of control system.

Thus the frequency response characteristics of a control system component can be obtained by substituting $j\omega$ for s in the operational expression relating input and output. The only restriction on this substitution is that the system be linear, i.e., that the descriptive differential equation be linear. To demonstrate the validity of the substitution of $j\omega$ for s let

$$\theta_3 = A \sin \omega t = Ae^{j\omega t} \tag{5}$$

where A = amplitude of input wave and the last term is the exponential equivalent of the second term. Then insert the exponential form of θ_3 in Equation (3), and also insert

$$\theta_4 = Be^{j\omega t} \tag{6}$$

on the assumption that the output will also be a sine wave. Carry out the indicated operation noting that the derivative with respect to time of $e^{j\omega t}$ is merely $j\omega e^{j\omega t}$ from which it follows that

$$B = \frac{A}{1 + j\omega T_b} \tag{7}$$

and

$$\frac{\theta_4(j\omega)}{\theta_3(j\omega)} = \frac{1}{1 + j\omega T_b} \tag{8}$$

The frequency response characteristics are obtained by separating Equation (8) into its real and imaginary parts and plotting in a complex plane, that is, in a plane with an imaginary vertical axis and a real horizontal axis. Multiply numerator and denominator by $1 - j\omega T_b$ to get

$$\frac{\theta_4(j\omega)}{\theta_3(j\omega)} = \frac{1}{1 + \omega^2 T_b^2} - j\frac{\omega T_b}{1 + \omega 2 T_b^2} \tag{9}$$

The first term on the right-hand side is the real coordinate and the second term is the imaginary coordinate. This equation is plotted in Figure 3 for all frequencies from 0 to ∞. The length of the vector drawn from the origin to a point on the curve is the magnitude ratio (amplitude ratio) and the angle the vector makes with the real axis is the phase angle for the frequency at that point.

Thus the magnitude ratio is the square root of the sum of the squares of the coordinates,

$$\left|\frac{\theta_4}{\theta_3}\right| = \sqrt{\frac{1 + \omega^2 T_b^2}{(1 + \omega^2 T_b^2)^2}}$$

$$= \frac{1}{(1 + \omega^2 T_b^2)^{1/2}} \tag{10}$$

and the phase angle is

$$\psi = -\tan^{-1}\omega T_b \tag{11}$$

Note that the locus of all frequencies is a semicircle with a magnitude ratio of 1.0 at zero frequency, zero magnitude ratio at infinite frequency, and respective phase angles of zero and −90 deg.

The Bode diagram is a more convenient representation of frequency response characteristics because frequency is clearly identified and the effects of adding components can be handled more rapidly. Figure 4† is a Bode diagram for a typical first-order time lag and also for a second-order time lag produced by adding another first-order time lag.

Similarly the phase angle of a first-

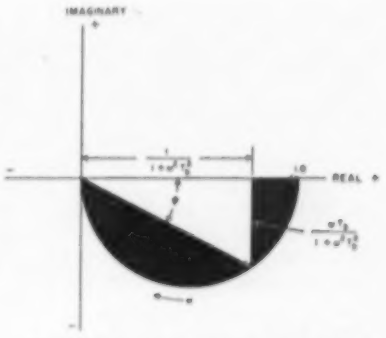

Fig. 3. Vector locus, output per input, first-order lag.

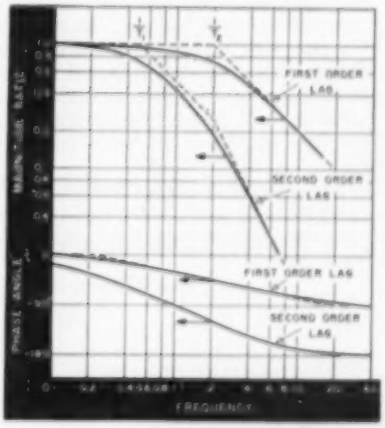

Fig. 4. Frequency response characteristics of time lags.

† Note that the characteristics may be approximated by the straight dashed lines on the diagram. For the magnitude ratio of a first-order lag the curve is horizontal at 1.0 at low frequencies up to $\omega = 1/T$, at which point it falls off with a slope of −1. With a second-order lag the plot falls off with a slope of −2 at $\omega = 1/T_b$ where T_b is the smaller time constant of the two lags.

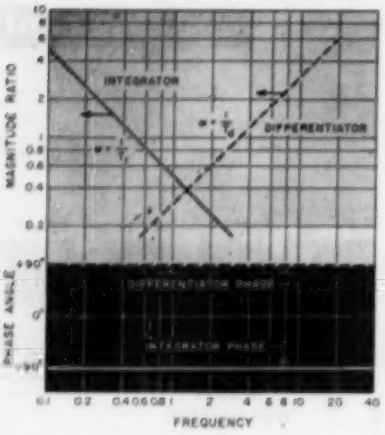

Fig. 5. Frequency response of differentiator and integrator.

order lag may be approximated by a straight line commencing at zero at a frequency one order of magnitude less than $\omega = 1/T$ and ending at -90 deg. at a frequency one order of magnitude greater than $1/T$. At lower and higher frequencies the approximation is 0 and -90 deg. respectively. For the second-order lag merely add the angles for the two first-order lags. Thus the maximum phase angle for n first-order lags (or one nth order lag) is $-90n$ deg.

Time Delay

The time delay holds back signals with time but unlike the time lag does not attenuate them.

It is called also *transportation lag* or *distance-velocity lag* or dead time. In Figure 1 there is clearly a time delay between the fluid in the kettle and the thermometer. If there is no appreciable heat exchange between the discharge pipe and its surroundings, the fluid in the pipe will undergo no temperature change on leaving the kettle, but a finite time, given by the ratio of distance to velocity, will elapse before the thermometer can sense the kettle temperature.

As indicated in Figure 2, the transfer function for a pure time delay, i.e., one involving no attenuation of signal, is given by

$$\frac{\theta_2(s)}{\theta_1(s)} = e^{-T_d s} \tag{12}$$

where

$T_d = \dfrac{l}{v}$ the distance-velocity lag, sec.

l = distance between kettle and thermometer, ft.

v = fluid velocity, ft./sec.

Equation (12) may be derived from the fact that the output of the delay at t is equal to the input at $t - T_d$. The series expansion of the ratio of output to input is identically the series expansion of $e^{-T_d s}$.

To get the frequency response characteristics, put $s = j\omega$ and rewrite the exponential in its trigonometric form $e^{-j\omega T_d} = \cos \omega T_d - j \sin \omega T_d$. From trigonometric identities the magnitude ratio is

$$\left| \frac{\theta_2}{\theta_1} \right| = 1 \tag{13}$$

and

$$\psi = -T_d \tag{14}$$

Thus the time delay does not affect the magnitude ratio, but it introduces a lag angle (negative phase angle) which increases without limit as frequency increases. This latter characteristic is objectionable since it can produce phase lags of 180 deg. at relatively low frequencies, thereby promoting system instability.

Integrator

The system of Figure 2 has a proportional controller. In Part I of this article it was pointed out that proportional control will tolerate a steady-state error. The magnitude of this error can be computed for the system of Figure 2 as follows:

$$\text{Let } \frac{\theta_b(s)}{\theta_e(s)} = G(s) \tag{15}$$

where $G(s)$, called G of s, is the transfer function for the controlled process exclusive of the controller,

$$G(s) = \frac{K_1 K_2 e^{-T_d s}}{(1 + T_1 s)(1 + T_2 s)(1 + T_3 s)} \tag{16}$$

In terms of frequency response the transfer function is written $G(j\omega)$.

The steady-state error expressed as fraction of the set point is

$$\left| \frac{\theta_e - \theta_b}{\theta_e} \right|_{\omega=0} = 1 - \left| \frac{\theta_b}{\theta_e} \right|_{\omega=0} \tag{17}$$

Since $|G(j\omega)|$ at $\omega = 0$ is $K_1 K_2$,

$$\left| \frac{\theta_b}{\theta_e} \right|_{\omega=0} = K_1 K_2 \tag{18}$$

and since for a proportional controller

$$\frac{\theta_c}{\theta_e - \theta_b} = K_p \tag{19}$$

$$\left| \frac{\theta_e - \theta_b}{\theta_e} \right|_{\omega=0} = \frac{1}{1 + K_1 K_2 K_p} \tag{20}$$

Thus the steady-state error decreases with increased proportional gain K_p. If this gain must be kept low to maintain system stability, the steady-state error will be large, and an additional control action will be needed to eliminate the error.

A general expression for the ratio of error to command is as follows:

$$\frac{(\theta_e - \theta_b)(s)}{\theta_e(s)} = \frac{1}{1 + G(s)G_c(s)} \tag{21}$$

where

$G_c(s)$ = controller transfer function

$G(s)$ = process transfer function including all components, except the controller.

Since $G(s)$ is fixed by the nature of the process, the only means of eliminating the steady-state error is to use a control function $G_c(s)$ or in particular $G_c(j\omega)$ which will approach infinity as the frequency goes to zero. Integral control provides this function.

By definition integral control generates an action which is proportional to the time integral of the deviation. The rate of control action, then, is proportional to the deviation:

$$\frac{d\theta_c}{dt} = K_i(\theta_e - \theta_b) \tag{22}$$

where

K_i is a constant.

In practice integral control is usually added to proportional control so that the transfer function of the controller is

$$\frac{\theta_c(s)}{(\theta_e - \theta_b)(s)} = G_c(s) = K_p\left(1 + \frac{1}{T_i s}\right) \tag{23}$$

where T_i = integral time, sec.

Integral control action is also called automatic reset, and instrument manufacturers frequently scale their integral controls in terms of the *reset rate* in repeats per minute, which is the reciprocal of the integral time in minutes.

From Equation (23) it is clear that the magnitude of $G_c(j\omega)$ becomes infinite as $\omega \to 0$. The frequency response characteristics for an integrator are shown in Figure 5. Since integral control increases the phase lag of the loop, it decreases the stability of the control system.

Differentiator

As shown also in Figure 5, the frequency response characteristics of a differentiator are the reverse of those of an integrator.

Derivative control stabilizes the control loop because of the positive phase angle, thereby permitting the use of higher proportional gains and corresponding faster control response. The transfer function for proportional plus derivative control is

$$\frac{\theta_c(s)}{(\theta_e - \theta_b)(s)} = K_p(1 + T_d s) \tag{24}$$

where T_d is the *derivative time* or *rate time*, usually specified in minutes.

Since derivative action produces a controller output proportional to the

time rate of change of the deviation, it is incapable of keeping the deviation small and hence must necessarily be used in conjunction with proportional control. More frequently it is used with both proportional and integral control, and the combination is called *three-mode-control*.

Representation of Real Processes

These control system components have been assumed to have lumped parameters, that is, their resistances and capacitances act at points in the circuit. Actually, many chemical engineering processes have distributed parameters; specifically, thermal processes have distributed conductances and capacitances.

Distributed systems involving resistance and capacitance may be represented in the limit by an infinite number of coupled RC stages. Since an important characteristic of these systems is a phase lag which increases without limit with increasing frequency, it is possible to represent them by a combination of two or three RC stages coupled to a time delay. The proper time constants must be selected empirically except for simple cases.

Example

The system of Figure 1 may be used to illustrate how frequency response characterization provides a simple yet quantitative means of working out a controlled system design. The direct problem of determining the type of controller necessary for satisfactory operation of the system can be considered with the following assumptions:

1. Heating and cooling fluids are recycled so rapidly through the kettle jacket that their change in temperature is very small and the jacket-side film coefficient of heat transfer is very large.

2. The ratio of the total heat capacity of the average kettle contents to the heat flux through the kettle wall per unit temperature difference between jacket fluid and kettle fluid, WC_p/UA, is equal to 20 sec., where W = kettle fluid mass, C_p = heat capacity of kettle fluid, U = over-all heat transfer coefficient, and A = effective heat transfer surface area corresponding to U. This ratio is the time constant of the kettle.

3. Temperatures are uniform throughout the fluid in the kettle.

4. The feed into the kettle is at a small but constant rate such that fluid leaving the kettle takes 3 sec. to reach the thermometer in the line. There is no detectable change in temperature in flowing through this line.

5. Experimental studies on a mixing valve and heating jacket identical with those of this system show that a step change in the air pressure on the control valve causes the jacket temperature to rise immediately and come within 63% of its new steady value in 6 sec. The range of temperatures available for the full range of controller output (12 lb./sq.in. air pressure) is 1.2 times the full range of the measured temperature.

6. The thermometer is a high-speed thermocouple with a time constant of 2 sec.

From these assumptions one can identify the constants shown in the operational functions as follows:

$T_1 = 6$ sec. since the valve-jacket system behaves like a first-order transfer stage, and the time constant of such stages is equal to the time for 63.2% response to a step function.

$K_1 = 1.2$ on the assumption that the full range of controller output corresponds exactly to the full range of controlled variable for $K_p = 1.0$.

$K_2 = 1.0$.

$T_2 = 40$ sec.

$T_3 = 3$ sec.

$T_4 = 2$ sec.

Inserting these numbers into the appropriate equations for magnitude ratio and phase angle (Equations (10), (11), and (14)) permits computation of the frequency response characteristics of the four process components. The magnitude ratios are multiplied together and the phase angles are added to get the over-all frequency response characteristics of the open-loop exclusive of the controller. Tables 1 and 2 and Figure 6 present the results of the calculation.

At the critical phase angle of −180 deg., the ultimate frequency is 0.197 radians/sec. and the corresponding process magnitude ratio is 0.175. Thus the ultimate proportional gain for this process is 0.175^{-1} or 5.7. For stable control it would be necessary to set the proportional gain at about half this ultimate gain or about 3, which gain would tolerate load errors of 25% of any load change. Since a reasonable offset might be 5%, proportional control alone is unsuitable for this system. Integral control must be added to reduce the offset. A satisfactory adjustment of the integral time is to set it equal to the ultimate period, in this case $2\pi/60(.197)$ or 0.53 min. The corresponding reset rate would be 1/0.53 or 1.9 repeats/min.

Thus the solution to the direct problem is that a proportional plus integral controller must be used for this system. Since the predicted settings of the control actions, $K_p = 3$ and $T_i = 0.5$ min. are well within the typical ranges of commercially available control instruments, no special instrument design is necessary.

The inverse problem can be solved in a similar manner. Suppose the control system has been installed with a narrow-band proportional controller. These instruments are relatively inexpensive, but since their practical range of proportional gain is from 10 to 50 they would invariably make the present system unstable.

The problem is to determine a simple

Table 1.—Open-Loop Magnitude Ratio

ω rad./sec.	a $\frac{1.2}{(36\omega^2+1)^{1/2}}$	b $\frac{1}{(400\omega^2+1)^{1/2}}$	c $\frac{1}{(4\omega^2+1)^{1/2}}$	abc
.01	1.20	.98	1.00	1.17
.02	1.20	.93	1.00	1.11
.04	1.17	.78	1.00	.91
.1	1.03	.45	.98	.45
.2	.77	.24	.93	.17
.4	.46	.12	.78	.04

Table 2.—Open-Loop Phase Lag (negative phase angle) (deg.)

ω rad./sec.	a $\tan^{-1}6\omega$	b $\tan^{-1}20\omega$	c $\frac{360}{2\pi}(3\omega)$	d $\tan^{-1}2\omega$	a + b + c + d
.01	3	11	2	1	17
.02	7	22	3	2	34
.04	13	39	7	4	63
.1	31	64	17	11	123
.2	50	76	34	22	182
.4	68	83	69	39	259

means of eliminating the oscillations. One possibility, of course, is to replace the narrow-band controller with a proportional plus integral controller. If the controller must not be replaced, then the rest of the loop components must be altered so that the magnitude ratio at the ultimate frequency is greatly reduced. This reduction can be effected either by changing the control valve linkage so that its gain is decreased from 1.2 to about 0.5 or by eliminating the dead time of 1 sec. by inserting the thermometer directly in the kettle. Removing the dead time increases the ultimate frequency by decreasing the over-all phase lag, and the corresponding magnitude ratio of the process decreases greatly. The dashed curve in Figure 6 is the phase angle exclusive of the dead time. It can be seen that the frequency at −180 deg. has increased to 0.34 rad./sec., and the new ultimate magnitude ratio is 0.064, hence $K_{p_0} = 1/0.064 = 15.6$. Thus at the minimum gain of $K_p \sim 10$ the system would be stable, although the gain margin K_{p_0}/K_p of 1.6 is less than the recommended 2.5 (*3*).

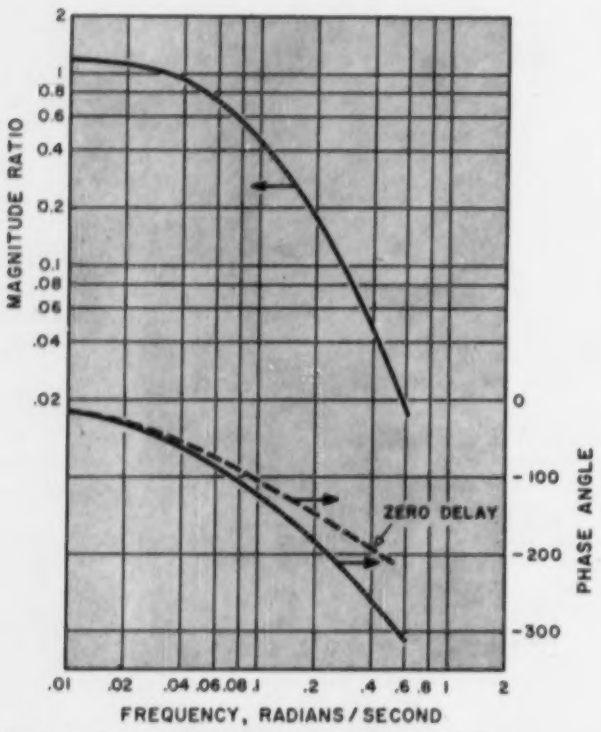

Fig. 6. Open loop frequency response, heat transfer control system.

The foregoing example has shown how frequency response analysis can be applied quantitatively to a simple process control problem.

It must be remembered that the frequency response techniques require that the components' behavior be linear. Fortunately automatic process control is concerned primarily with small changes, and for small changes all processes may be presumed to behave linearly.

Implicit in our treatment of the example is the assumption that resistances and capacitances may be lumped. This assumption is not valid for systems like shell-and-tube exchangers and packed contacting towers. Although such systems frequently can be approximated by simple combinations of lumped transfer stages and time delays, there are as yet no general rules for predicting what are reasonable approximations. Chemical engineers can make an important contribution to control theory by developing such rules.

At the present time frequency response characterization provides the simplest means of handling process control problems quantitatively. For many processes it is not possible to compute the frequency response properties theoretically, but often they can be measured on similar process units. Once these data are in hand for the components of the system they can be combined readily as shown in our example, and from the over-all characteristics the controllability can be assessed and the whole control system synthesized.

The constantly increasing trends toward the use of automatic control on increasingly broad process systems require the process-oriented skills of the chemical engineer. A convenient guide in this area is frequency response characterization. Parts 1 and 2 of this article have attempted to describe this characterization in sufficient detail and perspective to encourage its use.

Notation

A = constant
A_b = heat transfer surface of thermometer bulb
$B = A/(1 + j\omega T_b)$
C_{p_b} = heat capacity per unit mass of thermometer bulb
d = differential operator
e = base of natural logarithms
$G(j\omega)$ = transfer function, ratio of output to steady-state sinusoidal input
$G(s)$ = transfer function, ratio of Laplace transforms of output to input
$j = \sqrt{-1}$
K = constant
K_p = proportional control gain, reciprocal of fractional proportional band
l = distance
s = Laplacian operator (Laplacian complex variable)
t = time
T = time constant
U_b = heat transfer coefficient at thermometer bulb surface
v = velocity
W_b = mass of thermometer bulb
ψ = phase angle
θ = process variable (temperature)
θ_a = fluid temperature
θ_b = bulb temperature
ω = angular frequency, radians/sec.

SUBSCRIPTS

o means zero deviation
b " thermometer bulb
c " set point (command)
o " output

More refined techniques for handling frequency response data and more rigorous means for analyzing some process dynamics can be found in the various works listed in Literature Cited of Part 1 (*2*) of this article. Unfortunately there is still no single reference dealing in detail with chemical engineering process control.

Literature Cited

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2. Johnson, E. F., *Chem. Eng. Progr.*, **51**, No. 8, 353 (1955).
3. Oldenburger, R., *Trans. Am. Soc. Mech. Engrs.*, **76**, 1135 (1954).

The analog computer installation at the Du Pont Engineering Research Laboratory. Various computing or function units, integrators, coefficients, adders, function generators, and multipliers are in the two equipment racks on the left. The third and fourth racks contain various switching and synchronizing equipment. Oscilloscopes for observing solutions are located on both sides of the computer and necessary power supplies on the lower right. A Polaroid-Land camera is attached to one oscilloscope as a means of permanently recording solutions for further study.

ELECTRONIC ANALOGS IN REACTOR DESIGN

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During the past decade the development of automatic computers has received considerable attention in the popular and technical press. The emphasis has quite naturally been upon the design and methodology of computers, and only recently have their application to diverse types of technical problems received systematic attention. Of the computer applications reported to date, the majority have been in the fields of ballistics, aerodynamics, and related problems. The purpose of this paper is to point out a number of useful applications of one type of computer to a variety of chemical kinetics and reactor design problems.

Automatic computers are generally classified as either digital or analog. Use of digital computers in solving certain kinetic problems has been described (*1, 2*). Analog computers may be subdivided further into electrical or nonelectrical types and the electrical into direct and operational (indirect) analogs. The direct electrical analog computer consists of nonactive components (i.e., resistors, capacitors and inductors) and is beginning to find many applications in solving linear multidimensional problems of steady-state heat flow, transient heat flow, and fluid flow (*3, 5, 6*). The operational analog or electronic differential analyzer employs electronic amplifiers and feedback circuits to provide a wider variety of mathematical operations than is possible with the direct analog. The details of how such computers function have been described by Korn and Korn (*4*). The particular operational analog to be considered in this paper is available commercially.* Although similar to other electronic differential analyzers in most respects, it differs in that it provides solutions repetitively at a frequency of 60 times/sec. This high-speed operation permits the display of the solutions on a cathode-ray oscilloscope in the form of plots of one variable against another. One feature of this mode of operation is that the effect of introducing a change in the value of some parameter is directly and immediately observable as a change in the shape of the oscilloscope plot. This is advantageous in solving certain trial-and-error problems, which will be described here.

* The basic computer consists of components manufactured by G. A. Philbrick Researches, Inc., Boston, Mass., together with some additional components and modifications made at the Du Pont Engineering Research Laboratory.

Computer Applications in Kinetic Studies

Such operational analog computers as are described here are principally useful in solving ordinary differential equations, including linear and nonlinear or simultaneous systems of such equations (and hence higher order equations). It should be noted, however, that operational analog computers are not suitable for direct solution of partial differential equations since the one independent computer variable (time) cannot be used to represent the two or more independent variables involved in partial differential equations.

Many problems in reactor performance are characterized by sets of ordinary differential equations. Analytical solutions to kinetic rate equations are available for comparatively simple mechanisms in isothermal operation; but in the more general case dealing with simultaneous, consecutive, and reverse reactions, and particularly where the differential equations contain nonlinear terms, analytical solutions are unknown. It is in this area that computers can help. Expectation that the analog computer would contribute to the solution of reaction and reactor design problems was in fact one of the principal reasons for its acquisition by the Laboratory. During the past four years, the computer has been used to assist in the solution of a considerable variety of reactor problems. Since there has been little or no discussion of such uses in the literature, it has seemed likely that a review of the techniques involved and the experience acquired may be of value to chemical engineers engaged in reaction kinetics and in reactor design work.

The utility of analog computers in reaction problems arises from the ease with which many varieties of performance information can be developed that would be difficult or impossible to obtain in other ways. To aid in visualizing how such information can be obtained from an analog study, it is helpful to examine some physical factors involved in different classes of reaction problems, how inclusion of these can modify the mathematical formulation, and how this mathematical formulation becomes the controlling factor in computer setup and application. The following points may serve as an aid to classification of an analog approach to reactor problems:

Problems

1. STEADY-STATE AND UNSTEADY-STATE OPERATION

The only independent variable available in the use of an operational analog computer is time. This independent variable on the computer may be used to represent one independent variable in the reactor, which will either be time or a position coordinate in the reactor. In the most general case, dependent variables such as concentrations may be functions of both time and one or more position coordinates, but this situation leads to partial differential equations which, as noted before, cannot be solved on an operational analog. Thus, a reduction has to be accepted in the number of independent variables; even with this restriction, a variety of problems of industrial importance can be treated.

If time in the computer is assigned to represent time as the single independent variable in the reactor, then all manner of unsteady-state problems can be handled. That is, the assumption is made that concentration does not depend on position in the reactor. This corresponds to the constant-environment case where because of mixing effectiveness, concentrations can be assumed equal at each point in the equipment or in any one stage of the equipment under consideration.

Alternatively, time as the independent variable in the computer can be assigned to represent a position coordinate in the reactor providing that dependent variables, such as concentrations at fixed points, do not vary with elapsed time. The principal case of interest here is the steady-state operation of a continuous-flow reactor. Dependent variables such as concentration are functions of distance measured in the direction of flow and concentration gradients are assumed not to exist in directions transverse to the flow. In this case, there is also a fixed, simple relationship between position along the length of the reactor and time of contact since reactants entered the reaction system. Because of this unique relationship, concentrations can be considered as functions of either position or of time of contact. Differential equations expressing reaction kinetics are sometimes written in one form and sometimes in the other.

This restriction on whether concentrations are to be considered functions of time only or of position only places no theoretical limit on the number of dependent variables that can be handled either in the continuous-flow or the unsteady-state case. Thus, multiple, simultaneous, or consecutive reactions can be studied by representing the concentration of each different chemical compound as a suitable dependent variable in the analog setup and by including an appropriate number of differential equations to tie down the kinetics and the stoichiometry of the reaction system.

2. ISOTHERMAL AND NONISOTHERMAL OPERATION

In any single problem the temperature may be considered as a constant parameter, or alternatively as a dependent variable. These correspond respectively to isothermal or to nonisothermal operation. Under isothermal conditions, the reaction-rate factor, k, and equilibrium factor, K, are constant parameters that depend on the temperature selected but are nonvarying during a particular computer run. In the nonisothermal case, k and K are dependent variables whose values change as the temperature changes within the reactor. The functional relationship between k or K and temperature must be specified (usually in Arrhenius exponential form), and an auxiliary relation between the temperature and other dependent variables must be provided (usually as a heat balance).

3. ENGINEERING AS WELL AS KINETIC SITUATIONS

In addition to the set of kinetic differential equations that specify the rates of chemical change, often there will be a second set of differential equations that specify the rate of physical transfer processes or process transients. These equations may be needed, for example, to describe such factors as heat transfer, mass transfer, material accumulation, or action of control instrumentation. The effect of changes in these factors on over-all performance is frequently the area of greatest interest to chemical engineers. Dealing with them generally introduces such difficulties that calculation is practical only through use of an automatic computer.

EXAMPLES

Illustrations of these basic considerations in undertaking reaction problems are included in the examples to be described below. It might also be added that so far the problems here studied with the computer have been cases which are homogeneous or could be treated as homogeneous gas- or liquid-phase reactions. Hence, in this paper, heterogeneous reactions of the types which require consideration of concentrations in two or more phases entering into the reaction will not be discussed. There is no basic reason, however, why use of the computer should be limited to homogeneous systems and applications will undoubtedly be extended to heterogeneous systems as well.

1 SEQUENTIAL REACTIONS—STEADY-STATE, ISOTHERMAL

In isothermal reactions where the temperature is constant at every point in the reactor, the values of k (reaction rate factor) and K (equilibrium factor) are also fixed. This means that the differential rate equations (giving concentration changes with time of contact), together with algebraic equations relating concentration and the basic stoichiometry, are sufficient to specify completely the system.

Two of the more important types of problems that arise in isothermal studies are the following:

(a). Given experimental data on the composition of reaction products as a function of time of contact (or reciprocal space velocity), and either knowing or assuming the form of the rate equation involved (i.e., mechanism), determine the pertinent rate constants.

(b). Given the rate equations and rate constants, determine the distribution of reaction products as a function of contact time or reciprocal space velocity for one or more ratios of feed ingredients or levels of reactor temperature.

It is interesting to note that although one problem is essentially the converse of the other, from a computer standpoint both are handled with the same physical setup of the analog and with essentially the same computational steps.

Illustration of Case (a)

The procedure is illustrated which involves data reduction, i.e., finding the best values of the rate constants. Figure 1 shows a set of rate equations describing a sequence of consecutive reactions such as might be encountered in pyrolysis or in a polymerization process and a repre-

sentative plot showing changes in concentration of reaction products with reaction contact time.

1. From the original differential equations obtain a corresponding set of computer equations. This is accomplished by "scaling" (nothing more than the introduction of linear transformations for each variable in the equation). Scaling is required so that the excursions of computer variables (voltages) remain within the operating range of the computer (±50 v.) no matter what the numerical range of the concentrations they represent may be and so that coefficient settings are also within the dial range. This step may involve trial and error in nonlinear problems.

2. From the scaled equations a computer block diagram is drawn. The block diagram for the sequential-reaction problem is shown in Figure 2. The block diagram is constructed in the following manner: first, the scaled differential equations are rearranged so that the highest derivative of each dependent variable stands on the left-hand side as shown. For simplicity in explaining the diagram, however, all scale factors introduced in step 1 have been omitted. Starting with the equation for A and at the upper left of the block diagram, a voltage coresponding to $dA/d\theta$ is assumed. This is integrated with respect to the independent variable, θ, in the I-unit to obtain A. The computing unit performs the integration with zero initial condition, hence the required initial value of A, $A(0)$, is added into the adder unit. The variable A is now available for display and further manipulation as required by the equations. The coefficient unit is set at k_1; hence, from the negative output there is $-k_1A$. This is exactly equal to $dA/d\theta$ by the rate equation and the voltage representing $dA/d\theta$ which was originally assumed has been made available. The formation of the rest of the block diagram proceeds similarly with the squaring unit designated by S and the square root by T. It has also been assumed that B and C are initially zero and hence do not require the addition of initial conditions. The circuit is easily modified if this latter assumption is not made.

3. The block diagram serves as a wiring diagram from which the computer is set up. The necessary coefficient dials are set and initial conditions are introduced. (Values are set exactly if known, or arbitrarily if they are to be determined by trial-and-error fit.)

4. The computer setup is checked over. The various computer units are checked for electrical "zero" or balance. In solving nonlinear problems it is expedient to have one independent solution with which to verify the computer solution and estimate the over-all accuracy. This can be obtained by numerical or step-by-step solution of equations using a desk calculator or digital computer.

5. Computer solutions are obtained for the desired conditions. It is convenient in many cases to record the oscilloscope plots photographically for future reference. In carrying out the analog solution it is well to compare the computer solutions with the independent check solution at regular intervals, thus providing a check on the reproducibility of the results.

The length of time necessary to carry out the preliminary Steps 1 through 4 varies considerably from one problem to the next, ranging from an hour or two to as much as a week. The time-consuming steps are the 1st and 4th. Scaling a nonlinear problem is facilitated if a systematic procedure is used. Several scaling systems are possible, one of which has been described in the literature (*7*).

The unknown rate constants are determined as follows:

1. After the differential rate equations have been "scaled" they are set up on the analog computer. Values for the unknown reaction-rate constants are arbitrarily chosen and inserted as settings of the coefficient units. Computer solutions are then displayed on an oscilloscope.

2. Experimental data, i.e., the curves of concentration vs. contact time, θ, are plotted on a transparent plastic sheet which is then placed in front of the oscilloscope tube.

3. Settings of the coefficient units of the computer corresponding to each of the unknown rate constants are adjusted systematically until the computer solution displayed on the oscilloscope coincides with the experimental curves plotted on the transparent mark. The values of the rate constants then can be obtained from the dial readings.

In essence, the set of differential rate equations has been solved for a large number of combinations of rate constants and from these the set has been picked which corresponds to the experimental curves. In doing this, it might be noted that exactly the same computer setup would be used in solving problem (b), i.e., knowing the rate constants, find the product distribution for different ratios of reactants or levels of reactor temperature.

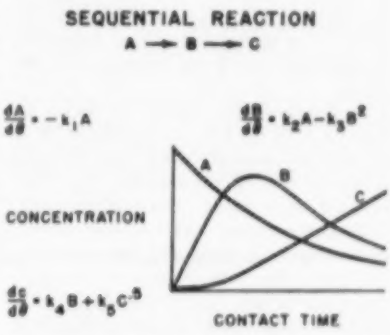


Fig. 1. Sequential reactions for which rate constants, k, are to be found. Kinetic rate equations and reaction product distribution are shown.

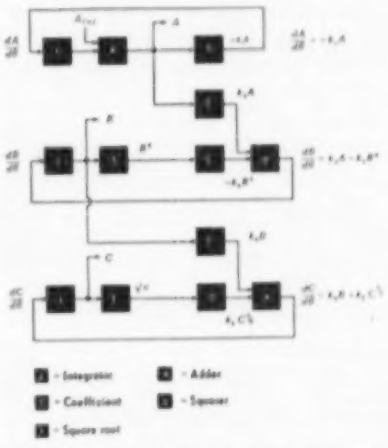


Fig. 2. Differential equations and computer block diagram for sequential reaction problem.

2 NONISOTHERMAL REACTION—STEADY STATE WITH HEAT TRANSFER

The nonisothermal reactions are rather more complex than the problems discussed so far, but they represent, at least industrially, the cases more frequently encountered. In addition to the complexities of the differential rate equations, one must now recognize that the reaction rate factor k and perhaps the equilibrium factor K are no longer constant but are functions of temperature. The rate factor and equilibrium factor are commonly of the Arrhenius type, i.e., $k = \exp(A - B/T)$. Further, temperature will usually be a function of position in the reactor. By writing heat balances on a differential-length basis, the temperature change can be expressed as a function of the heat released or absorbed in the reaction, the heat transferred across the reactor walls, and the feed temperature. Except for the truly adiabatic case, no analytical solutions are known for nonisothermal problems. Graphical or arithmetic integration methods have been used but are quite tedious in practice.

Computers offer perhaps the most practical means available for the study of nonisothermal problems. When the necessary equations are set up and solved on the computer, one has in essence a mathematical model of a reactor which can be operated in a manner similar to a pilot plant; that is, one can experiment with operation at different pressure levels, preheats, cooling-water rates and temperatures, different equipment sizes, and many other conditions. From the mathematical "pilot plant" one is able to observe temperature and conversion profiles which permit interpretation in the same way as with conventional pilot-plant data. Reasons for using the mathematical model and computer solution are that since results are obtained quickly, parameters can be investigated that would be uneconomical or impossible in an actual pilot plant.

a. Heat Exchanger-Reactor Example

In order to demonstrate the analog computer approach, a heat-exchanger reactor is considered such as the ammonia-synthesis converter discussed in the literature by C. Van Heerden (*8*). The form of the kinetic differential equation involved in this problem is complex enough to require some care in deriving a practical block diagram. In addition this example illustrates the utility of a high-speed analog computer in handling two-point boundary conditions.

A sketch of the reactor is shown in Figure 3. The converter consists of a cylindrical catalyst vessel with a large number of countercurrent heat-exchanger tubes inside. The cold nitrogen-hydrogen mixture enters at the bottom, flows upward through the heat-exchanger tubes and downward through the catalyst bed. A substantial portion of the heat generated in the catalyst bed in the exothermic reaction is removed by heat exchange to the cooler nitrogen-hydrogen feed.

The net rate of ammonia formation is the sum of the synthesis and decomposition rate as expressed in the following dimensional rate equation developed by Van Heerden.†

$$\frac{dz}{dx} = \left\{ \frac{(2.41)(10^{10})}{u} p^{-0.5}(1+z)(1-z)^{1.5} \right\} \cdot \left\{ 0.105 K^2 p^2 \frac{(1-z)^2}{z} - \frac{z}{(1-z)^2} k_2(T) \right\} \quad (1)$$

$$k_2(T) = \exp\left\{ -\frac{20{,}000}{T} \right\} \quad (2)$$

† Equation is presented in the same form as given by Van Heerden, with dimensions of parameters and variables in working units.

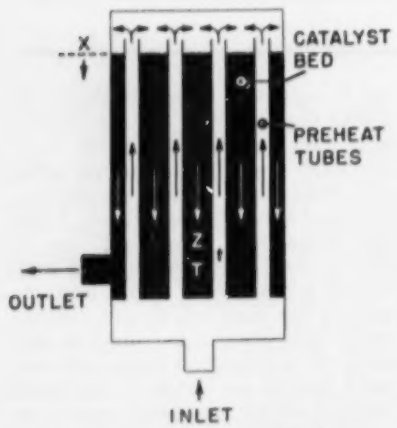


Fig. 3. Heat exchange converter for ammonia synthesis.

A differential heat balance in the reaction zone results in

$$\frac{dT}{dx} = \frac{\Delta H}{wc_p}\frac{dz}{dx} - \frac{U\pi d}{wc_p}(T-t) \quad (3)$$

and in the preheat zone

$$\frac{dt}{dx} = -\frac{U\pi D}{wc_p}(T-t) \quad (4)$$

It is to be noted that the equations, as written, apply only to one tube and its associated volume of catalyst. It is assumed also that at any point along the tube uniform conditions exist across the cross-section.

For the present discussion it is convenient to rearrange Equation (1). Assuming as Van Heerden does that pressure and linear velocity are constant parameters, replacing the equilibrium factor term, K^2, with the ratio of synthesis and decomposition rate factors, and multiplying $k_1(T)$ and $k_2(T)$ respectively by all constant terms applying to $k_1(T)$ and $k_2(T)$ so

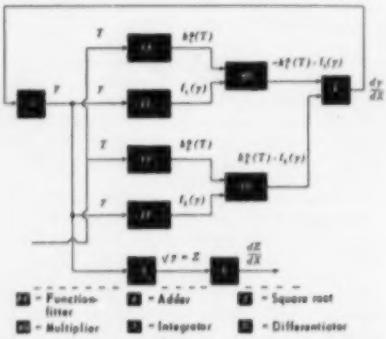


Fig. 4. Computer block diagram for Equation (7) (ammonia synthesis converter).

as to obtain new terms $k^*_1(T)$ and $k^*_2(T)$, Equation (5) is obtained

$$\frac{dz}{dx} = k^*_2(T) \cdot \left[\frac{(1+z)(1-z)^{0.5}}{z} \right] - k^*_1(T) \left[\frac{z(1+z)}{(1-z)^{0.5}} \right] \quad (5)$$

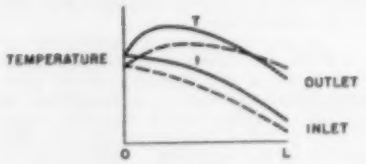
where

$$K^2 = \frac{k_2}{k_1}$$

The computer setup involves several features not previously mentioned. Each rate factor, $k(T)$ is simulated by the use of an arbitrary function generator. The input to the unit is T, the temperature of the reaction zone, and the output is $k(T)$. In this particular problem the rate factor is given by an Arrhenius-type equation; however, one could just as easily employ other forms of k vs. T data. This function-fitter approximates functional relationships by means of ten straight-line segments which can be varied independently in length and slope by means of twenty potentiometers located on the front of the unit.

The two groups involving z on the right-hand side of Equation (5) present some difficulties for analog solution if carried out in the most obvious way by developing $(1+z)$, $(1-z)^{0.5}$ and $(1-z)^{0.5}$ and

AMMONIA SYNTHESIS TEMPERATURE DISTRIBUTION



$$\frac{dT}{dx} = \frac{\Delta H}{wc_p}\left(\frac{dz}{dx}\right) - \frac{U\pi D}{wc_p}(T-t) \qquad T=t \text{ AT } X=0$$

$$\frac{dt}{dx} = \frac{U\pi D}{wc_p}(T-t) \qquad t=t(0) \text{ AT } X=L$$

Fig. 5. Temperature distribution in synthesis converter with internal heat exchange.

then performing the variable multiplication and division. The fractional powers of 3/2 and 5/2 could be obtained using the "squaring" unit which can be calibrated to provide exponents of 3/2 and 5/2 rather than 2. Variable division is a rather difficult operation to perform accurately, particularly if the denominator approaches zero as it does in the present example. If this literal approach were used, a rather large number of computer components, particularly multipliers, would be required. A smaller number of components would be desirable in order to reduce setup and "zeroing" or checking time. The possible zero divisor for $z \to 0$ in the second term of Equation (5) is eliminated by multiplying through by $2z$ and making use of

$$2z\frac{dz}{dx} = \frac{d(z^2)}{dx}.$$

Defining $z^2 = y$, Equation (6) is obtained.

$$\frac{dy}{dx} = k^*_2(T) \cdot [2(1+\sqrt{y})\ (1-\sqrt{y})^{0.5}] - k^*_1(T) \cdot \left[\frac{2(y)\ \cdot\ (1+\sqrt{y})}{(1-\sqrt{y})^{0.5}} \right] \quad (6)$$

$$\frac{dy}{dx} = k^*_2(T)\ \cdot f_2(y) - k^*_1(T)\ \cdot f_1(y) \quad (7)$$

Since f_1 and f_2 are functions of y alone, additional function fitter components are employed, thereby eliminating a considerable number of other units. The resultant circuit for solving Equation (7) is shown in Figure 4.† The block diagrams for Equations (3) and (4) are derived in a straightforward manner.

In addition to satisfying the differential equations, the solution must satisfy initial or boundary conditions. For the rate equation this is handled as discussed in the first example. A typical temperature distribution is shown in Figure 5. The temperature equations must satisfy

$T = t$ when $x = 0$

$t = t(0)$ when $x = L$

When solving such differential equations graphically or by stepwise numerical integration, one ordinarily starts at one end of the reactor with given values

† dz/dx, needed in the heat balance, is obtained by taking the square root of y to obtain z, then differentiating z in a D unit.

of T, t, and y and integrates step by step until the other end is reached. In this reactor problem, the two known or specified temperatures are at opposite ends of the reactor. Thus, at $x = L$, y and T are unknown. At $x = 0$, the temperature at the top of the reactor is unknown. In order to solve the problem by usual mathematical methods, a trial-and-error approach is required as described by Van Heerden. This consists of assuming temperatures at the top of the reactor and carrying out the integration repeatedly until the correct t at $x = L$ is obtained. Van Heerden suggests a way of correlating the results so as to make maximum use of all the information obtained; however, this process must be repeated each time conditions in the reactor are changed. It is apparent that this would lead to considerable work if the problem were to be studied by numerical integration.

In solving this problem on an analog computer, the same trial-and-error procedure is used; however, in the case of the high-speed analog, one voltage is adjusted corresponding to $T = t$ at $x = 0$, i.e., the initial conditions for the temperature equations. At the same time t on the oscilloscope is displayed and compared at $x = L$, with a reference voltage.* The coefficient unit supplying the voltage corresponding to the initial value of t and T is then adjusted until the value of t at $x = L$ displayed by the computer corresponds to the reference value of t at $x = L$. The whole trial-and-error procedure requires less time than it does to describe the procedure. Boundary conditions specified at two points occur frequently in reactor studies and the high-speed analog has proven extremely well suited in handling this type of problem.

* Standard high-speed computer technique includes the use of an electronic switch permitting simultaneous display of two voltages or computer solutions on the oscilloscope.

UNSTEADY-STATE OPERATION

The case of unsteady-state operation is also of considerable importance industrially. For flow systems employing tubular reactors, a case exists where concentration is a function of both time and location, and no longer can time and location be uniquely related as was done in Equation (1) for the continuous-flow converter. In practice one can study unsteady-state processes if one is able to represent composition as a function of only time, i.e., concentration is independent of position in the reactor. Two common types of reactors shown in Figure 6 in which it is assumed that perfect mixing is obtained satisfy these requirements.

For the sake of clarity in explanation the following discussion is limited to simple first-order kinetics; analog solution of more involved cases would be carried out as has already been discussed in the two previous examples. The continuous case will be treated first. Equating the accumulation of the reactant with concentration z to the sum of disappearance of reactant by reaction and net change due to flow, $z_0 - z$, between inlet and outlet, the following equation is obtained:

$$\frac{dz}{d\theta} = -k_1(T) \cdot z + \frac{w}{V\rho}(z_0 - z) \quad (8)$$

where $k_1(T) = \exp\left(A_0 - \frac{B_0}{T}\right)$

A differential heat balance equating accumulation to heat generated by reaction plus heat transferred to the jacket plus the net heat carried in by liquid flow results, after rearrangement, in

$$\frac{dT}{d\theta} = \frac{\Delta H}{c_\rho} k_1(T) \cdot z - \frac{UA}{Vc_\rho\rho}(T - t_j) + \frac{w}{V\rho}(T_0 - T) \quad (9)$$

The equations for a batch reactor are obtained if w, the throughput, is put equal to zero. The batch equations are of the same general form as given earlier for the tubular reactor, Equations (1) and (3), and, except for definition of constants, the analog treatment is identical. For the continuous-feed case where w can be treated as a constant, only four linear computer units need be added (two adders and two coefficients) to include the terms $w(V_0 - z)/V\rho$ and $w(T_0 - t)/V\rho$. Permitting w to vary would require the use of variable multipliers. It is obvious that concentration plots can be obtained as a function of time by straightforward computer solutions.

Since time is now the independent variable, one may study the dynamic behavior of the combined reaction and heat transfer process. Process dynamics are of particular interest in automatic process control. It is possible to study the dynamic behavior of such nonlinear processes and at the same time include analog simulation of control equipment. It is rather straightforward then to determine stability regions for any mode of control, operating condition, or process disturbance. It should be pointed out that the control information obtained with the computer is the transient behavior for step disturbances and not the more common sinusoidal response encountered in control work.

Figure 7 illustrates a fairly typical control problem involving reaction kinetics and heat transfer in a continuous-flow, constant-environment reactor. In this particular case, the process temperature is measured and used to control the steam-jacket temperature, t_j. With the control situation illustrated and the assumption that the controller incorporates proportional plus reset control, the analog would require additional units to implement the following equation:

$$t_j = \alpha_1(T_s - T) + \beta_1 \int_0^\theta (T_s - T)\,d\theta \quad (10)$$

where α_1 and β_1 include the controller gain settings and the temperature-pressure relationship in the steam jacket. This example illustrates a rather simple type of automatic control loop. Much more complex control problems can be studied as long as appropriate differential equations can be written to describe the dynamic contribution of the control loop and associated process elements.

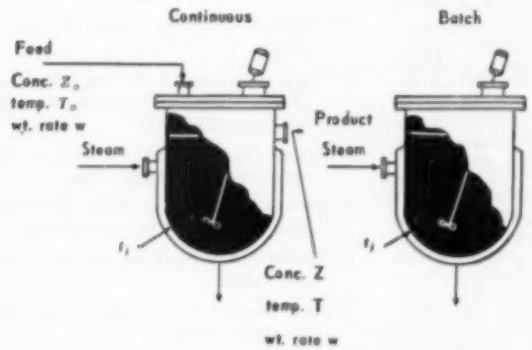


Fig. 6. Constant-environment reactors for continuous or batch operation.

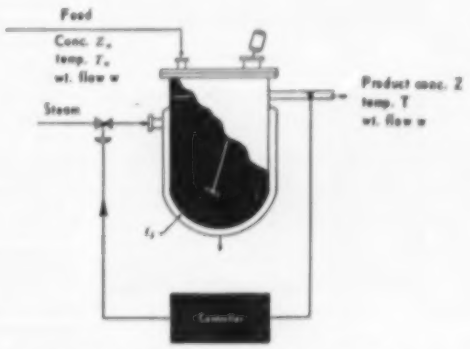


Fig. 7. Continuous-flow reactor with automatic control loop.

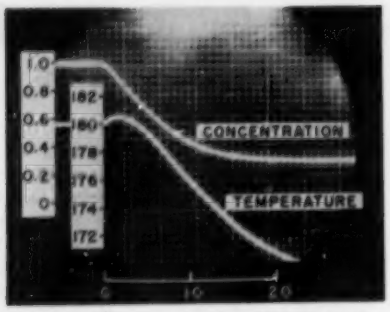


Fig. 8. Oscilloscope photograph of analog solutions to a set of nonisothermal reactor equations.

Advantages and Limitations of Operational Analog

The computational advantages of the high-speed or repetitive operational analog as compared to manual, digital, or low-speed operational analog solution depend largely on the speed with which individual solutions are obtained. This, in turn, permits economical solution where large numbers of solutions are required to carry out a trial-and-error process. Another advantage of the rapid solution is that it permits scanning a large region of the solution after which the unimportant regions are left and the more important are studied in detail.

The value of operational analogs in kinetic problems is mainly in the fact that rate equations may be rapidly solved without necessity of assuming isothermal operation. Use of the analog computer permits a more detailed study of the mathematical "pilot plant" of existing or proposed kinetic systems, thereby assisting in approaching optimum operation or in obtaining a sounder design. In the case of unsteady-state operation the analog permits study of the transient and control behavior under startup or other conditions differing from the small excursion region for which controls are usually designed. It is also obvious that the operational analog has many other applications. The high-speed analog is particularly well adapted to problems in other fields described by differential equations which would normally require trial-and-error solutions.

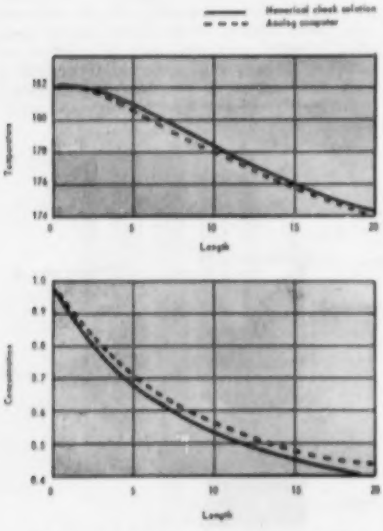


Fig. 9. Tubular reactor system check of analog solution.

In this discussion it is necessary, in all fairness, to point out the limitations of the operational analog. Since all analogs are dependent upon physical measurements, there is always a limit on the ultimate accuracy. The analog computer should not be considered when extreme precision is required; precision is more naturally the field of the digital computer; however, in practice the high-speed operational analog is found to have sufficient accuracy for the majority of technical problems of the types discussed here. Accuracies will vary from 1 to 5% of full scale (i.e., of 50 v.). Reproducibility of results is considerably better, provided reasonable care is taken in checking the computer. The components limiting the accuracy of the high-speed analog are found to be the oscilloscope used for output, the multiplier units, and other nonlinear units. As would be expected, nonlinear equations suffer most from component inaccuracy. Since it is our practice to compare computer operation against independent check solutions, it is possible to determine the expected accuracy for any given problem. Figure 8, for example, shows a photograph of an oscilloscope face on which are displayed analog solutions for temperature and concentration profiles in a typical nonisothermal tubular reactor. In this particular problem, the computer consisted of twenty-four individual units. A comparison of these analog results with numerical check solutions calculated on a digital computer is shown in Figure 9. With care it is possible to maintain comparable or better reproducibility over periods of at least a month. As mentioned previously, the time required for scaling, obtaining a check solution, calibrating, zeroing, and otherwise maintaining accuracy leads to a considerable fraction of the total time required to solve a problem. In problems of roughly the complexity described here, from twenty to 100 solutions would have to be required before it would be considered economical to consider operational analog solutions.

The operational analog is limited for the most part to solving ordinary differential equations. Partial differential equations can be solved only when it is possible to restate them in the form of ordinary differentials. Several techniques have been described for accomplishing this, but in any case the possibilities are rather limited. In solving nonlinear equations one is limited in the number of nonlinear factors which can be incorporated. This is because the inherent inaccuracies of such components tend to cascade, thereby reducing accuracies below an acceptable level. At the present state of development in the computers described here, a problem is limited to not more than six major nonlinear units. In solving kinetic problems it has been found that the most serious trouble occurs in generating the Arrhenius-type rate factor. A rough rule states that a rate factor will double for each 10° C. increase in temperature. With this rule, a 100° increase would cause better than a 1,000-fold change in the rate factor. In general, the resolution obtained with analog computers enables the covering of a 100-to-1 range with acceptable accuracy; hence in fitting rate constants with function generators one is restricted to the case where temperature changes are limited to about 50° to 70° C. variations. This can be a rather severe limitation in certain kinetic problems.

Notation

A,B,C = mole fraction of reactants in sequential reaction problem
A_i,B_i = constants in Arrhenius-type Equation, $i = 1, 2, 3$
A = heat transfer area in constant-environment reactor
c_p = specific heat at constant pressure of reaction mixture
D = diameter of heat exchanger tubes
f = function
ΔH = heat of reaction
k = reaction-rate factor (constant at a fixed temperature)
k° = product of reaction-rate factor and other constant coefficients
K = equilibrium factor (constant at a fixed temperature)
L = length of synthesis converter
p = total pressure in reactor, atm.
t = temperature of fluid outside reaction zone, ° K.
T = temperature of fluid inside reaction zone, ° K.
v = superficial gas velocity in catalyst vessel
U = over-all heat transfer coefficient
V = volume of constant-environment reactor
w = weight rate of flow
x = distance from top of synthesis converter
y = x^2 by definition
z = mole fraction of reactant or product
α,β = controller constants
ρ = density
θ = contact time

SUBSCRIPTS

0 means at inlet to reactor
1 reverse reaction
2 forward reaction
s set point
j jacket

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LIQUID-METAL HANDLING

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The stimulus of nuclear reactor development has produced many technological advances of general interest. Use of liquid or molten metals as a means of conveying heat is one of them. When the idea first came up, it seemed a simple enough thing to do and the potential advantages in a large variety of industrial processes ranging from reaction kettles to reheat for steam turbines were so obvious that it was difficult to resist the temptation to tackle them all and nuclear reactors too.

Since these early days much time and effort have been expended on the subject and it has become somewhat easier to see the field in perspective.

The advantages inherent in the use of liquid metals for the transport of heat are fairly obvious, the difficulties much less so.

The greatest attraction of liquid metals is due to their high boiling points combined in favorable instances with low melting points; this enables liquid heat transfer processes to be carried out over wide temperature ranges. Table 1 gives a comparison of a number of liquids.

Not all the substances mentioned are either readily available or suitable as heat transfer fluids.

Water, not mentioned in the table, is an exceptionally good heat transfer medium with relatively few limitations. These limitations are, however, of such specific importance in nuclear energy applications that they have provided the stimulus for the development of alternative coolants.

The first difficulty with water is the critical temperature of 374° C. which sets a rather low limit to the upper temperature of any heat engine cycle if the heat is to be supplied by circulating water. Moreover, high-temperature water requires inconveniently high pressures for its containment.

A more specific difficulty is due to the nuclear properties of hydrogen. The absorption cross section for thermal neutrons is fairly high.

In addition water is the most effective substance for slowing down neutrons and this leads to difficulties in some designs of thermal reactors and excludes it altogether for fast reactors. Organic liquids have the same disadvantages to a greater or lesser degree in addition to limited stability under high temperature and irradiation.

The situation might fairly be summarized by stating that in the case of the fast reactor we are forced to liquid-metal coolants, whereas in the case of thermal-power reactors there are great potential advantages to be set off against the difficulties of introducing a new technology.

Reactivity

The first difficulty to be met in the use of liquid metals is their chemical reactivity.

The alkali metals are of course particularly reactive and will, at elevated temperatures, burn spontaneously in air. The heavy metals are less reactive in this obvious way but seriously toxic. The fire or toxicity hazard which arises with these high temperature fluids is incidental. Their reactivity makes it in any case essential that they should be most carefully confined. All the metallic oxides are corrosive and some alkali metals form in contact with air nitrides, hydrides, and hydroxides as well, all of which lead to serious corrosion troubles as well as the danger of plugging critical points of a flow circuit.

Table 1.—Comparison of Liquids

Substance	Melting Point ° C.	Boiling Point ° C.
Di-2-naphthylamine	171	471
Tetra aryl silicate (TAS 160)	< −20	427
Triphenylamine	125	365
2-4'-biphenyldiamine	45	363
4 Bromodiphenyl	90	310
2 Naphthyl-phenyl-methane	55.5	350
Diphenyl-diphenyloxide	182 *	400 *
Caustic soda	318.4	1390
Arsenic tri-iodide	146	403
Sulfuric acid	10.5	330
Heat transfer salt ($NaNO_3$ + $NaNO_2$ + KNO_3)	200 *	550 *
Sulfur	120	444.6
Mercury	−38.87	357
Gallium	29.92	1983
Rubidium	39.0	688
Potassium	63.7	760
Sodium	97.8	883
Lithium	179	1317
Sodium-potassium	−12	785
Lead-bismuth	125	1670

* usable range.

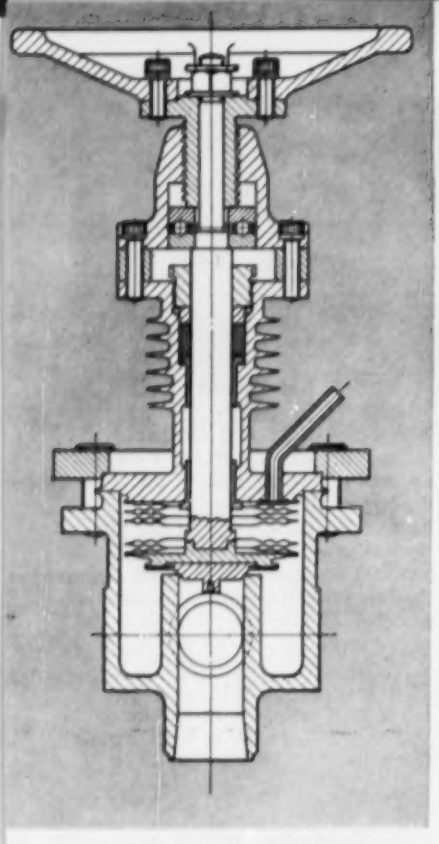

Fig. 1. Frazer-Nash sodium valve.

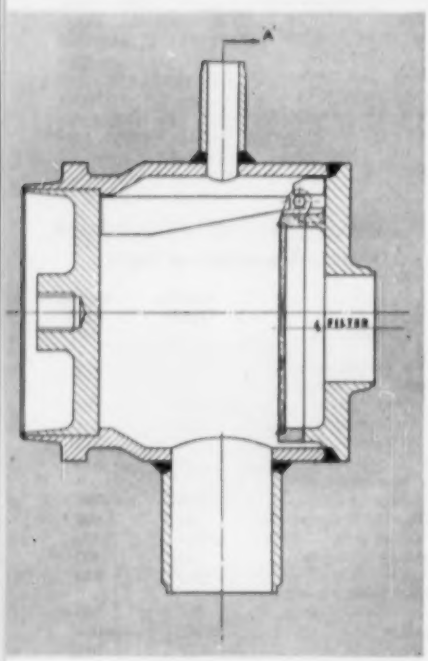

Fig. 2. Flap filter for sodium.

Leak Tightness

In all liquid-metal applications it is therefore of prime importance that the whole plant should attain a high standard of leak tightness and that any gas atmosphere present over free surfaces in the plant should be completely inert.

Freedom from leakage is an onerous demand and can be met only with a good deal of specialized experience, particularly when the alkali metals are used, which at high temperatures are certainly the most searching crack-detectors. On the whole it is useful to model one's procedure of assembling and testing a liquid-metal plant *on customary high vacuum techniques.* That is to say, one proceeds by assembling components first and assembling them into the plant after they have been proved leaktight. It is well to remember that two separate requirements have to be met: one is to establish leak rates, if any, and the other to find the leaks.

It is important to ensure that no potential leaks are blocked or covered during manufacture or assembly by slag, paint, oil, or the like which would be attacked subsequently by the liquid metal.

For this reason it is *inadvisable* to use, for instance, coated electrode arc welding where a small slag inclusion might give a perfect seal under test but provide a leakage path by reaction with the liquid metal. Experience would indicate that it is best to separate functions and make seal welds by the inert arc technique and take structural loads separately. This can be done either by using edge-welding as the seal and bolts to take the structural loads or by making a buttweld with an inert arc sealing run on the inside followed by a metallic arc structural weld over it. With care excellent results can be obtained either way provided scrupulous cleanliness is observed. It should be remembered also that all joints must be tested before they become enclosed or inaccessible in further stages of assembly. The drawing of a 1-in. sodium valve (Figure 1) shows an assembly by edge-welding throughout, including the diaphragm stack bellows, which has proved satisfactory in high-temperature service. In this instance both the weld on the gas backing line and the welds on the bellows stack are tested before final assembly. The pipe stub at the bottom shows the customary preparation for a buttweld made as described above.

Inert Gas

Once a leaktight plant has been assembled a supply of inert gas is required. With sodium or potassium, helium, argon, or nitrogen may be used as inert atmosphere and preference must be decided on grounds of cost and convenience. With lithium a rare gas is essential but with lead a reducing atmosphere, e.g., hydrogen, may be useful.

In any case a high standard of gas purity is essential, particularly where gas pressure is used to displace liquid from one vessel to another so that large gas quantities come in contact with the liquid.

The type of gas purification train used is again largely a matter of personal preference and many types have been used successfully. In the author's experience an argon purification train consisting of a calcium packed tube at 600° C. followed by a Na-K bubbler has proved satisfactory and trouble free in service. It is difficult to determine the allowable contamination of blanket gas since the concentrations of oxygen or water involved are not measurable by any straightforward method. In practice it is relatively easy to observe an exposed area of liquid-metal surface in contact with the gas and get an exceedingly sensitive indication of any objectionable impurities which may be present. If such a test is satisfactory in that no clouding of the surface appears within a minute or so, no trouble will be experienced.

Start-up

However clean the assembled plant and the available gas may be, further steps are necessary to get a clean liquid circulating at high temperatures. For the original filling it is strongly advisable to evacuate the plant and remove adsorbed gas and moisture by warming with trace heating if possible. The plant then should be filled with purified inert gas and carefully evacuated a second time. After that the vacuum may be used to suck in the liquid metal from a storage tank. It is usual to bring in the liquid metal through a filter of the sintered stainless steel type to keep back any suspended oxide which may be present in the tank. When the circuit is filled and brought up to temperature, remaining traces of contamination in the plant will be picked up slowly by the liquid metal; this results as a rule in a higher oxide concentration than is advisable. If the plant is small and satisfactorily vacuum tight a final purification can be achieved by heating the liquid metal to the highest tolerable temperature in the circuit and dumping it hot back to the storage tank, letting it cool there and bringing it back again several times. With the marked increase of oxygen solubility with rising temperature, this procedure gives a satisfactory clean-up.

In larger plant this method is not convenient and one should therefore provide a cold trap, that is, a by-pass line in which a small amount of the liquid metal is taken out of the circuit, cooled near to its freezing point, filtered or settled in a packed tank, and then returned. If such a cold trap is the point of lowest temperature in the circuit, all oxide in excess of the solubility at cold-trap temperature will eventually be deposited there.

Pumping

The pumping of liquid metals can be

done in a variety of ways, which have been described in the literature. The possibility of making electromagnetic pumps without moving parts is one of special interest, particularly for nuclear reactors where the presence of intense radioactivity makes pump maintenance all but impossible. The principle of all electromagnetic pumps is quite simply the interaction of force, current, and magnetic field at right angles to each other. Almost an unlimited number of ways of designing such pumps can be put forward and most of the more promising solutions have been investigated to a greater or lesser extent.

It has become customary to distinguish between conductive and inductive pumps, that is, pumps in which the "armature" current is supplied externally or induced internally. Both d.-c. and a.-c. conductive pumps have been built and operated successfully with sodium but the latter are most useful in small sizes. Conductive pumps, the d.-c. variety in particular, are likely to collect gas in solution or suspension in the liquid metal on the conductor pole pieces and this can lead to severe reduction or complete interruption of performance. This effect, if unsuspected, can lead to much trouble which is difficult to track down. A momentary switching off of the current releases the gas so collected, but the only cure for the trouble is careful degassing of the circuit and prevention of gas entrainment at free surfaces. Inductive pumps do not show this obscure phenomenon.

Induction-type electromagnetic pumps now have practically eliminated all other pumps for large flow rates—at any rate of sodium. The theory and design are well understood, the manufacture is akin to normal electric machinery and their reliability is proved by many thousands of hours of operation.

The best efficiencies attained in operation are in the order of 35% for sodium and appreciably lower for sodium-potassium alloy.

Operating temperatures are limited to 300 to 350° C. depending on whether or not air cooling is applied to the windings. This applies to pole pieces wound by conventional techniques. Higher temperatures of operation are undoubtedly possible, but they await the development of new and unorthodox winding and insulating methods.

It is a notable feature of liquid-metal plants that all the elementary components as well as the specialized devices have to be designed and developed from scratch; no standard equipment has proved adequate. The valve shown in Figure 1 is one example, showing how a satisfactory design for liquid metals differs from, say, a water or steam valve.

Pilot Plant

As illustration of the kind of design experience which has been built up it may be worth while to quote some details of the experimental sodium-steam superheater-test plant built by Foster-Wheeler at Egham.

Steam—6,400 lb./hr.—is circulated at 1,000 lb./sq.in. and dropped from 1,025° F. (552° C.) to 735° F. (390° C.) in giving up heat to sodium in one heat exchanger and reheated by the circulating sodium in a second heat exchanger from 600° F. (316° C.) to 820° F. (438° C.). The steam then goes on through an oil-fired superheater where it is brought back to the original top temperature. The upper and lower temperatures in the sodium circuit are 900° F. (482° C.) and 680° F. (360° C.) respectively. The sodium is circulated by three small a.-c. conduction-type pumps in parallel at a rate of 15,600 lb./hr. These pumps were chosen because they happened to be available at the time as the only pumps suitable to operate at 360° C. continuously.

At the time of writing, about 1,500 hr. of operation of the plant have been accumulated. Much useful information has been gathered and the original design has been well justified. The basic purpose of the plant was to prove whether simple, single-tube heat exchangers could be operated safely with steam on one side and sodium on the other under severe practical conditions. Both heat exchangers are identical and each consists of a pair of exchangers in series. These in turn each contain bundles of 24⅜-in. tubes, 16 S.W.G., in U formation, about 13 ft. long and welded to their respective tube plates. The steam is on the shell side and all parts of the plant touched by sodium are of austenitic stainless steel and welded throughout.

Mishaps

Several instructive mishaps have occurred. Owing to corrosion from the water side, one tube has failed inside the tube plate but not at the weld. Steam entered the sodium circuit and the resulting pressure broke the bursting disks and most of the sodium in the circuit was discharged through it. There was no fire and no damage to adjacent tubes or other parts of the plant. The clearing out of the sodium hydroxide incrustation of the plant caused a lot of trouble.

One pump channel developed a fatigue crack, possibly due to incipient cavitation caused by too low a static pressure in the sodium circuit. The fault was detected by observing a slight smoke trail from the affected pump. No fire occurred, the leak being a small one. It proved possible to go through normal shutdown procedure and wash out the sodium circuit before removing and replacing the pump. About one pound of sodium had leaked out.

A fair amount of oxide plugging was experienced in the early part of the operation. At the time there was no cold trap in circuit, the sodium being cleaned on admission through the filter shown in Figure 2. Cold trapping cured the complaint.

The preheating of this plant is done by tracing all pipes with electric heater wire, placed underneath mineral wool insulation. It was found necessary to cover the circuit with a complete set of thermocouples to indicate conditions during warming up before sodium filling. Much time was wasted without them.

The whole plant is so laid out that it will drain completely and that is undoubtedly an important feature, much inconvenience being caused during cleaning even by auxiliary gas lines where the same principle had not been observed.

Cleaning

Many different cleaning procedures have been tried or proposed and the choice is not an easy one. Cleaning with water jets in the open air is dangerous, even with relatively open pieces of plant. Hydrogen-air explosions always occur and much damage is caused to more delicate items, even with the greatest care.

Evacuation and admission of low-pressure steam with continuous evacuation of the hydrogen formed is quite a safe method and readily controllable. The disadvantages are corrosion troubles from the caustic soda formed and the likelihood of plugging smaller passages and trapping metallic sodium behind solid caustic soda. But in suitable cases and with care the method can be satisfactory.

Cleaning with alcohol is not advisable because soapy addition compounds form and block the passages and are difficult to dislodge. Small pieces contaminated with sodium or sodium-potassium are readily and safely cleaned in a deep vessel of acetone with added dry ice. The carbon dioxide slows the reaction and keeps the liquid cool while at the same time providing a gas blanket which effectively prevents the ignition of rising hydrogen bubbles.

The sodium-steam plant described is equipped with an ammonia-cleaning plant, permanently installed. Dry, liquid ammonia is the only practicable substance which will take sodium into true solution. Hence, it is possible to remove residues of sodium from a plant by washing with liquid ammonia without leaving behind any residues. Thus, a plant which has been operated with sodium and washed out with ammonia

can be opened to the atmosphere for inspection or alteration without danger of contamination by atmospheric oxygen or moisture or hazard to the operator. Moreover, there are no deposits or corrosion during cleaning to obscure whatever changes may have taken place on surfaces during operation. In the absence of oxide in the circuit ammonia cleaning is straightforward. If there are small amounts of oxide deposits, they can be cleaned out after the removal of the metal by a wash with a solution of ammonium chloride in ammonia followed by a further ammonia wash. With much oxide, especially with parts of the plant plugged, the process is difficult, but it seems likely that with a good system of monitoring concentrations in the washing streams even such difficult cases could be handled satisfactorily.

Safety

Fire hazards loom rather large when a program of liquid-metal work is first embarked upon, but they diminish rapidly with experience. None the less it is essential that adequate precautions be taken. The first thing is to minimize the hazards which could arise from a sodium leak. As a rule sodium will ignite spontaneously at temperatures above 400° C. (750° F.) but it can ignite at much lower temperatures. Water in any form must be kept away because of the great violence of the resulting hydrogen-air explosions. Concrete, moist sand and wood are dangerous. It is advisable to cover the floor below a sodium plant with an assembly of steel trays not more than 2 ft. square to catch leaks and allow fires to be put out easily, should one occur. Insulating materials must be tested for their reaction to hot sodium, because most of them react violently. Mineral wool of certain types is satisfactory.

Fire-extinguishing powders are available and so are suitable applicators, and even large fires can be put out in a few seconds by experienced operators, provided the fires occur in places which can be covered by the powder. In a fire, thick caustic smoke is produced in great volumes and this makes fire fighting most difficult in confined places. It is advisable to have powerful emergency ventilation to maintain some visibility, to provide easy access, and to install handrails or other guides as well as low-level safety lighting.

Two types of protective clothing are employed: one is the normal working outfit of fireproofed cotton laboratory coat, safety glasses, and plastic helmet, eyes and hair being the most vulnerable points for small splashes; and the other is full protective clothing for emergency. It consists of fireproof plastic helmet with additional aluminum top, safety lenses with fine wire gauze screens in front and respirator, cape to protect neck and shoulders, a press-studded coat which can be discarded instantly, polyvinylchloride gumboots and moleskin gloves. The cape and coat are made of a fine chrome tanned leather with seams covered by glued joints. Any stitched joints are attacked rapidly. Seams are so arranged that no small pools or droplets can be held by them. This outfit will protect the wearer against a shower or jet of red hot sodium. Identification marks are important, since it is impossible to tell people apart in such costume.

Fires are rare in practice, and therefore, it is important to have a thorough and regular fire-drill practice so that all concerned may acquire the necessary skill and confidence to cope with any emergency.

Based on a paper presented at the Geneva International Conference on the Peaceful Uses of Atomic Energy.

Criteria for selection of equipment for separation processes

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The presence of radioactive materials imposes restrictions on the selection of equipment above those that would apply for more conventional plant, and these restrictions must be taken into account when selecting a process. The extent to which servicing can be carried out governs the design specification and the type of equipment that can be employed. This is demonstrated by the classification of plant in the accompanying table.

Based on a paper presented at the Geneva International Conference on the Peaceful Uses of Atomic Energy.

An Activity Classification of Plant

Design and Servicing Implications

Grade	Total Activity Present in Cell	Possibility of Entering Cell	Design Notes
1. Extremely high activity	> 1,000 curies	No entry at all	No relaxing of design specification possible. All servicing must be done from outside shielding by remote control.
2. Very high γ-activity	100-1000 curies	Short entry (2-30 min.) after extensive decontamination, assuming ease of decontamination is made a feature of design of vessels and plant.	Slight relaxing of design specification is possible if plant is required for short-time service only. For plant required to work for a long life, Grade 1 design specification is necessary.
3. High γ-activity	1-100 curies	Entry possible after draining plant and a limited amount of decontamination, particularly if some local shielding is used.	Careful use of some conventional plant items may be permissible.
4. Low γ-activity	> 1 curie	Entry may be possible during operation, particularly if local shielding is used.	Conventional plant items can be used.
5. α-activity only	....	Entry possible at any level of activity for unlimited periods. (wearing protective clothing and mask).	Owing to intense toxicity, plant should be inside "fume cupboard" or "dry-box" type of cell and should be leakproof.

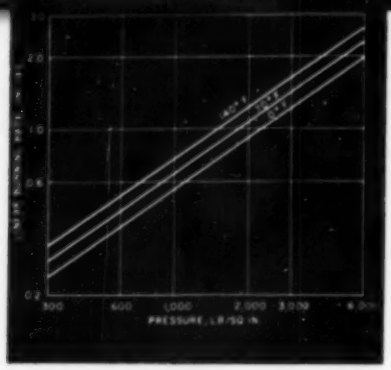

Fig. 1. Burning rates of JPN in rod form.

Solid propellants suitable for use in rockets have become important military materials. Many groups, both in government and in industry, are working on the problem of developing improved solid propellants for use in rockets. One group working in this field is located at the Naval Ordnance Test Station, Inyokern (NOTS), China Lake, California. This paper describes the facilities and the methods used at NOTS in developing double-base rocket propellants.

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small-scale facilities for development of DOUBLE-BASE PROPELLANTS

Of the several different kinds of solid propellants, this paper is concerned with the double-base variety. The origin of solid propellants lies in the gun field, where black powder was first used only to be displaced by smokeless powder consisting chiefly of nitrocellulose with a small amount of stabilizer present. This is known as *single-base* propellant.

The fluffy nitrocellulose was converted into the useful controlled granulations by plasticizing with ether-alcohol as a solvent and extruding the pasty material into cylinders or strips for drying. A stabilizer was added to absorb the products of decomposition of nitrocellulose, which are made slowly but continuously at normal temperature, and to remove them so that they would not make the further decomposition more rapid. In order to make the powder or propellant more powerful and faster burning, such materials as nitroglycerin were added later. These propellants were described as *double base*. It became apparent that nitroglycerin acted as a plasticizing agent itself, and ultimately the ether-alcohol solvent was dispensed with in certain compositions to allow the making of solventless powder.

The Germans and the British had used a solventless process for making large extrusions in which the removal of solvent would have been so slow as to prohibit the use of the normal solvent process of manufacture. When the solventless process for making rocket charges was tried in this country during World War II, the first composition used was that of trench mortar sheet. As the work progressed, the composition became more elaborate with the addition of various ingredients for one purpose or another. Typical compositions used in World War II are shown in Table 1.

Double-base propellants are essentially nitrocellulose-base plastics differing from commercial nitrocellulose plastics by their greater flammability. Their different ingredients fall into certain functional classes. A discussion of these will shed light on the basic problem of propellant development.

Nitrocellulose is generally classed in terms of the percent of nitrogen on a weight basis; standard grades produced in this country for military use contain 12.2, 12.6, or 13.4% N, other desired percentages being obtained by blending two different grades. Since cellulose is a variable product depending on many factors, specifications are hard to establish. It has been proposed that nitrocellulose might be replaced with a synthetic material, just as silk has been replaced by nylon for many uses, but the research problems involved are difficult.

An example of the explosive plasticizer is nitroglycerin. It has two functions: (1) to increase the energy of the powder and make it burn faster, and (2) to modify the physical properties of the nitrocellulose and produce the desired amount of flexibility and plasticity for extrusion while still retaining at least part of the mechanical strength of the nitrocellulose fibers.

Of the inert plasticizers, diethyl phthalate is one that is widely used. This exerts a major influence on the mechanical properties of the propellant and also reduces the total energy and the flame temperature of the burning powder gases. Because of this latter effect such ingredients have been described as *coolants*. By a proper balance of the three major constituents (nitrocellulose, explosive plasticizer, and inert plasticizer) desired energy, flame temperature, and mechanical strength can be obtained within a wide range.

Finally, minor amounts of other ingredients may be added to improve extrusion characteristics, for example, candelilla wax in the propellant having the military designation JPN (Table 1), or to ensure regular burning at all temperatures of use. The control of burning regularity can be illustrated by the effect of carbon black and potassium sulfate. Carbon black has the function of preventing radiation from the hot gases from penetrating much beneath the burning surface and causing burning to start there prematurely. Potassium sulfate improves the regularity of ignition and burning at low temperatures. The rate of burning of a propellant as measured in a direction normal to the burning surface, is chiefly a function of the pressure of the surrounding gases and of the original temperature of the propellant at the start of burning. The burning rate for JPN, as a function of pressure and temperature, is shown in Figure 1.

Process of Propellant Development

A solid rocket propellant which is adapted for service may have to be manufactured in enormous quantities for stockpiling, or for use in wartime. It is important that the techniques used in a propellant development program be such that one will have confidence that the same composition made in a production plant will have identical properties. To provide this confidence, a number of highly definitive performance tests have been developed in addition to precise methods of quantitative analysis. In the laboratory stage of development the concern here is with batches of propellant 1 to 10 lb. in weight. The preparative and evaluation techniques used at this stage are such that a propellant developed on this scale can be taken to 1,000-

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Table 1.—Solventless Propellant Compositions of World War II

Values in weight per cent.

Ingredient	JP	JPN	Russian Cordite
nitrocellulose	52.2	51.5	56.5
nitrogen content of NC	13.25	13.25	12.2
nitroglycerin	43.0	43.0	38.0
dinitrotoluene	....	.....	11.0
diethyl phthalate	3.0	3.25	.....
diphenylamine	0.6	.....	....
ethyl centrolite	....	1.0	4.5
potassium sulfate	....	1.25	....
potassium nitrate	1.2	.....	....
nigrosine dye (added)	0.1	.....	....
carbon black (added)	....	0.2	....
candelilla wax (added)	....	0.02	0.02

lb. pilot plant batches and on to full-scale production without encountering serious problems.

The steps used in propellant development at Naval Ordnance Test Station (NOTS) are as follows:

1. propellant manufacture, which includes obtaining the several ingredients; mixing the ingredients to form a paste; drying and aging the paste; rolling the paste to form sheets; and extruding the sheets into forms suitable for tests.
2. chemical analysis and stability tests.
3. mechanical and ballistic tests.

From as little as 1 lb. of the experimental propellant these steps, except mechanical strength tests, can be completed; given a 10-lb. sample all pertinent tests can be made. Whereas in actual practice one never goes from laboratory to production on the basis of a single 1- to 10-lb. experimental lot, it can be done with fair safety, provided the experimental lot demonstrated precisely the properties sought. The strand burning test is the key to this confidence. Prior to its perfection, which has taken place within the last few years, the development of a propellant required the testing of many 1,000-lb. lots in actual rockets before larger production could be considered. This obviously entailed greater cost.

Experimental Propellant Manufacture

The building at NOTS in which the propellant is made is constructed of heavy reinforced concrete and contains three operating rooms, each with an adjoining bay from which the operation can be watched through a heavy glass window. In the two rooms where liquid nitroglycerin is handled, the floors and lower walls are lined with lead and sloped to a drainage trough. These drainage troughs lead to an external catch box which traps any nitroglycerin which might be washed off the floors of the operating rooms. These trenches and the catch box are shown in Figure 2. The use of lead-covered floors is standard construction for buildings in which nitroglycerin is handled.

The steps used in manufacturing the propellant are as follows:

1. OBTAINING THE INGREDIENTS

All the ingredients, except nitroglycerin, are easily obtained from commercial sources and can be stored safely. Nitroglycerin, on a small scale, is obtained by batch extraction of nitroglycerin from Kieselguhr dynamite, which has been found to be safe and convenient.

This dynamite can be shipped by freight in 60% concentration, and the extraction of pure nitroglycerin is easily done with acetone. The extraction is accomplished by packing the dynamite loosely in aluminum columns which are 32 in. high and 5 in. diam., allowing acetone to percolate through the column and collecting it in a seamless copper container below the column. In a single extraction with a ratio of 1.5 lb. of acetone/lb. of 60% (nitroglycerin) dynamite, 95% nitroglycerin in the dynamite is recovered yielding an acetone solution containing 50-60 wt. % nitroglycerin. This solution is, for practical purposes, insensitive to shock, hence safe to handle.

The acetone solution of nitroglycerin cannot be used directly in the manufacture of solventless double-base propellant because of the great affinity of acetone for nitrocellulose; thus the nitroglycerin is removed from the acetone solution by the addition of water. In a 50 wt. % acetone-water solution at room temperature, nitroglycerin is soluble only to the extent of about 0.5%. This low solubility in water-acetone plus nitroglycerin's high sp.gr., 1.60, permit easy separation of the nitroglycerin from the water-acetone solution. After siphoning off the water-acetone, one additional water wash is necessary to reduce the acetone content in the nitroglycerin to a tolerable level (less than 3%). This remaining percentage is substantially removed during the subsequent slurry-mixing operation. Upon completion of the washing, the nitroglycerin is released through the bottom of the wash tank into a seamless copper vessel containing sufficient methanol to make the nitroglycerin content of the resulting solution 50% or less. Such a solution is safe to handle and the solubility of methanol in nitrocellulose is sufficiently low so that this solution can be used directly in the manufacturing process without any effect attributable to the methanol. Often the desensitizing agent, instead of being methanol, is the nonexplosive plasticizer which is to be used in the propellant formulation, for example, diethyl phthalate. Figure 3 shows the apparatus used for extracting nitroglycerin from Kieselguhr dynamite.

Fig. 2. Pilot plant for making solid propellant sheet. Drainage trenches and waste-collecting box shown in foreground.

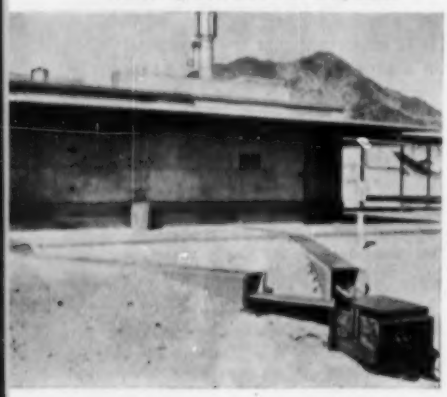
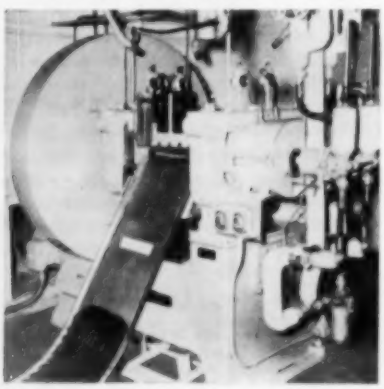


Fig. 3. Extraction columns and wash tank for recovery of nitroglycerin from dynamite.

Fig. 5. General view of trench mortar sheet rolls as installed. Photoelectric unit can be seen above rolls in center of four sprinkler deluge heads.



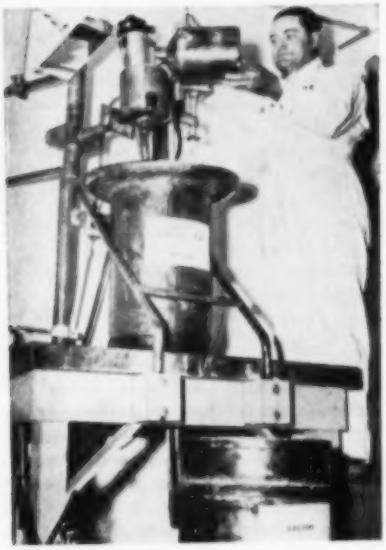


Fig. 4. Slurry-mixing process in operation. The stirrer for agitation can be seen above mixing kettle.

2. MIXING THE CONTENTS

The process used is a small-scale version of the slurry-mixing process used during World War II for double-base rocket production.

The process consists of slurrying nitrocellulose in water (water to nitrocellulose ratio 10 to 1 by weight) at 130° F. and adding the other water-insoluble ingredients while vigorously agitating the slurry. After thorough mixing, the contents of the mixing tank are filtered by a vacuum filter. Remaining on the filter is the nitrocellulose, plus absorbed plasticizer, stabilizer, and minor additives. This is the propellant "paste" which is still fibrous in nature and after filtration contains about 30% moisture. The mixing facilities at NOTS permit mixing of batches ranging in size from 1 to 10 lb.

These mixing facilities are shown in Figure 4. As an illustration of safety precautions which must be taken with nitroglycerin, it is noted that traps containing silica gel to collect water and nitroglycerin vapors are placed in the vacuum line to the paste filter to prevent any collection of nitroglycerin in the vacuum pump. As a further precaution the fluid used in the pump is dioctyl phthalate, an effective desensitizing agent for nitroglycerin.

3. DRYING AND AGING THE PASTE

After filtering, the paste is placed in a 130° F. oven in a closed metal box for a 24-hr. aging period to permit the plasticizers and stabilizer to diffuse throughout the nitrocellulose. After aging, the bag of paste is removed from the box and tray-dried at 130° F. until the moisture content is reduced to about 12%. Any water soluble ingredients are added to the propellant paste at this stage.

4. ROLLING PASTE TO FORM SHEETS

The dried paste is rolled on an 8-in. diam. differential-speed rolling mill. A general view of the rolls is given in Figure 5. This equipment was obtained from Radford Ordnance Works and is of the same model used during World War II to make trench mortar sheet propellant.

Owing to the number of fires incident to this operation, several safety devices are incorporated, including a temperature-actuated valve for the sprinkler system, a photoelectric actuating unit for the same system, and both manual and automatic stopping and reversing devices for the rolls. In addition, to draw off fumes produced in rolling as well as to reduce the spread of the flames in case of a fire, an exhaust duct with powerful fan is installed in the ceiling.

The roll equipment can be operated semiautomatically, the operator placing the paste charge on the rolls and then leaving the room to conduct the actual rolling from a position behind a reinforced concrete wall. At the conclusion of the rolling, a hydraulically operated "doctor" blade cuts the sheet, which adheres to the front or faster roll. The sheet which is stripped from the roll slides down the brass chute shown in Figure 5.

The 8-in. diam. roll mill which is used at NOTS produces a finished propellant whose properties closely resemble those of propellant produced on 14-in. diam. production rolls. On the 8-in. mill, a 1 lb. (moisture-free basis) charge is rolled at one time. Rolling is done at a mill temperature of 160 to 200° F., the average rolling time is 5 min., and the finished sheet propellant ranges from 0.025 to 0.040 in. in thickness. Wattmeter measurements indicate that the energy required to convert 1 lb. (moisture-free basis) fibrous paste with 30% moisture to 1 lb. of well-colloided sheet with 0.3% moisture is about 0.15 kw.-hr. This requirement of course varies from composition to composition and the value given is for a typical service propellant.

5. EXTRUDING ROLLED SHEETS

The differential-mill sheet propellant is formed into specimens suitable for mechanical and ballistic tests by extrusion. Two sizes of presses are used for extrusion, the larger having a barrel diameter of 3 in. and the smaller a barrel diameter of 1 in. They are hydraulically powered piston presses mounted in a vertical plane. The press barrels, in which the propellant is placed, are heated with oil, 130° F. being the average. The air can be evacuated from the press barrel before the ram begins to extrude the propellant through the die and in this way inclusion of air in the extruded shape is avoided. Figure 6 shows the 1-in. extrusion press.

The 1-in. press is used to extrude small strands of about 1/10 to ¼ in. diam., and the 3-in. press to extrude sections ranging from ½ to 1½ in. diam.; with suitable die assemblies still larger diameter sections can be extruded with the 3-in. press. The pressure, which it is necessary to apply to the press ram-head to extrude double-base propellant, varies from 3,000 to 10,000 lb./sq.in. depending upon composition, temperature, shape of product, and extrusion rate.

Chemical Analysis and Stability Tests

The first and the most direct control on the process is the chemical analysis. Unfortunately, the analysis of propellant is difficult and not so accurate as desired, hence other types of controls must also be utilized.

Another simple, accurate test is the heat of explosion, the isochoric-isothermal change in internal energy content ($\Delta E_{v,t}$) when the propellant burns in an inert atmosphere of either nitrogen or helium. The heat of explosion is measured by igniting a comminuted propellant specimen in a standard calorimeter which is pressurized with oxygen-free helium or nitrogen. Values for the heats of explosion of propellant ingredients are available, and using these as partial values and knowing the composition of the propellant, one can compute quickly an over-all heat of explosion which will agree within 2 to 5% of the experimental value. Thus by comparing the measured heat of explosion of a propellant with the value computed on the basis of chemical analysis one is able to obtain an over-all check on the accuracy of the chemical analysis.

Chemical stability as measured by the Taliani test (*1, 3*) is of primary interest in development work because all new propellant ingredients must be shown as chemically compatible with the other ingredients before they are incorporated into formulations. A further aspect of the measurement of the gas produced by using the Taliani apparatus is the relation of this measurement to the number of days a propellant grain can be held at elevated temperature before cracking

Fig. 6. 1-in. extrusion press shown being loaded with ram in upper position.

of the grain results from the internal production of gas.

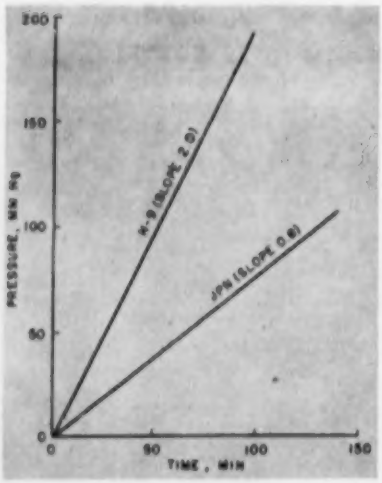
The Taliani apparatus consists of a small, closed sample tube containing finely divided propellant under nitrogen, or for some tests, air at atmospheric pressure. The test measures the change in pressure with time within the sample tube under conditions of 110° C. and constant volume. Typical results for two propellants are shown in Figure 7. Results of this test indicate how fast the propellant decomposes at an extreme temperature and are interpreted to show relative chemical stability at service temperatures. The Taliani test is not the only test of chemical stability which is used but it is a most important one because of its simplicity, speed, and good reliability.

Mechanical and Ballistic Tests

For the double-base propellant investigator, the most important test affecting the use of the propellant is the ballistic evaluation. This is partly because so many of the other properties can be reasonably predicted in advance.

The basic test used is measurement of the rate of burning of a 3/32-in.-diam. strand, burned cigarette fashion in an atmosphere of nitrogen at the temperature and pressure of interest. The equipment is shown in Figure 8, and is a modified version of that described by Crawford, *et al.* (*2*). The sample, which is coated with a flame retardant, can be seen mounted on a rack suspended from the heavy closure plug. Four fuse wires are inserted into the tiny strands at accurately measured distances. During the period of burning of the strand, these fuse wires melt in sequence, the melting of the first wire causing the three clocks to start; thereafter, the clocks are stopped in sequence as the remaining wires are melted through in their respective order. The burning rate over each of the three intervals then can be calculated. The volume of the strand bomb is sufficiently large so that the pressure stays nearly constant during the run.

Fig. 7. Typical pressures measured over a period of time in Taliani apparatus.



After the ballistic evaluation and with the assumption that the chemical and stability characteristics are reasonable, the next point of interest is the strength of the propellant. This is evaluated from different points of view, such as tensile strength, compressive strength, impact value, and torsion strength. From a theoretical point of view, all tests of this type resolve themselves into combinations of two basic strengths: shear and tensile. No single mechanical strength measurement suffices to characterize the behavior of a propellant in a rocket motor because of the enormously complex stress system to which a rocket grain is subjected.

For example, the piece of nitrocellulose plastic (rocket propellant grain) must stand up structurally over a temperature range as wide as −65 to +165° F. when subjected to applications of stress which sometimes approaches a rate of 500,000 lb./sq.in./sec. Because of the almost insurmountable technical difficulties in attaining tensile stresses of this magnitude, tensile strength is commonly measured at low rates of loading over a wide temperature range. This test is considered most important in characterizing the mechanical suitability of propellant. The tensile strength of a typical propellant at 70° F. and at a low rate of stress application is about 800 lb./sq.in.

Process Control

Careful observation of the propellant ingredients and paste during the various operations at the laboratory stage yields valuable and applicable information on the probable behavior of the ingredients under larger pilot plant and even production conditions. Variations of additional techniques under controlled conditions are studied in relation to the processing and the resulting propellant properties. For example, one may consider the addition of a water-insoluble but highly colored solid to the slurry. This may be added to the slurry water following the nitrocellulose, in which case it has to be ground very fine to get adequate distribution, or it may be dissolved in the plasticizers and used as an indicator of the uniformity of distribution of the plasticizer in the slurry.

Fig. 8. Burning-rate equipment for strand tests shown with mounted sample ready for insertion at right and three measuring clocks in middle. Nitrogen pressure used is registered on dial below clocks.

The rolling operation is a critical production operation because of the labor, power consumption, and capital investment required. A paste must adhere to the differential speed rolls, must form a strong, well-colloided sheet, and must have a minimum tendency to fire on the rolls. Study of these characteristics on the 8-in. laboratory rolls at various conditions of rolling time and temperature gives an estimate of production rollability.

The extrusion step is the last, but not least, important step of manufacturability to be considered. On a small scale, the conditions can be readily varied over a much wider range than that practicable with production equipment. Dies can be made for a specific purpose such as determining extrudability of various grain shapes. With newly developed techniques and equipment, propellant grains approaching the diameter of the press barrel can be readily extruded. This permits the testing of new formulations in typical rocket motors at an early stage of propellant development.

Summary

In conclusion then, it can be stated that the value of the small-scale propellant development facility just described lies in the ability of its users to predict reliability and fairly inexpensively the large-scale producibility and performance of a variety of new double-base rocket propellants.

Acknowledgment

Special acknowledgment is due Captain Levering Smith, U.S.N., for his support in the establishment of the facilities and program described; Harry S. Connable, for his contributions to the design of the facilities; and to F. A. Warren for his work in developing evaluation procedures.

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Presented at A.I.Ch.E. meeting, Louisville, Kentucky.

THE HERMETIC CENTRIFUGAL

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The separation of solids from liquids and the separation of immiscible liquids by gravity settling have been utilized since ancient times. Basic principles have been studied and various scientific laws enunciated to describe the rates of settling. It is known that particles of solids in liquids or droplets of a liquid will settle at definite rates, depending primarily upon their density, size and shape of the particles, and the viscosity of the surrounding media.

When centrifugal force is substituted for gravity settling, the process may be speeded up and made more efficient, but many basic laws still are applicable.

Suppose a dirty liquid is fed into a gravity-settling tank at a rate that passes it from the inlet through the outlet in 1 hr. If the tank is 3 ft. deep, all particles which settle more than 3 ft. in 1 hr. would settle to the bottom and be caught, whereas particles settling less than 3 ft./hr. would be swept out with the liquid. Suppose then that the gravity-settling tank is rebuilt and horizontal plates or partitions are placed every half foot to allow access for the feed and the effluent to each plate. At the same rate then, this settling tank would catch particles settling at the rate of 3 ft./hr. but it would also catch slower particles settling at rates down to ½ ft./hr. This is the basic principle of thin strata distribution.

If gravity separation is replaced by centrifugal force, the basic settling tank as illustrated in Figure 1A now becomes a crude separator bowl. By placing partitions in this separator, it now becomes a crude disc-type purifier bowl (Figure 1B). In the description of the settling tank, partitions with 6-in. spacings were used. In the modern-type centrifuge bowl, the discs or partitions are usually placed 30/1000 to 50/1000 in. apart for efficient and rapid separation. In the open-disc separator the feed material enters the bowl through the feed tube at the top and passes to the bottom of the bowl where it is distributed upward through holes in the discs. Particles of dirt travel through a film of liquid usually only 50/1000 in. in thickness (the space between two discs) before lodging on the collecting surfaces.

Fig. 1-A. Basic settling tank used as crude separator bowl.

Fig. 1-B. Addition of partitions makes separator a crude disc-type purifier bowl.

The Hermetic separator or pressure separator has all the advantages of the disc bowl with thin strata distribution and, in addition, operates under positive pressure. Its basic features are illustrated in Figure 2. The feed material enters at the bottom, passing into the rotating spindle and upward into the separating bowl.

The light and heavy phases are discharged under pressure at the top through separate seals into pipes which carry the separated phases to further processing or to storage tanks. By employing efficient mechanical seals at the inlet and outlets, pressures more than 150 lb./sq.in. have been used during centrifugal operation.

It has been known for some time that the longer the materials are held under centrifugal force, the greater the degree of separation. Increase in holding time may be accomplished by increasing the dimensions of the separator or by decreasing the throughput rate or more practically by using more discs with a steeper angle. From the principle of thin-strata distribution, it is also known that smaller spacings between the discs lead to more efficient separation. Owing to positive pressure on the liquids the designer of the Hermetic separator may take advantage of both these facts and therefore may design with steep angle discs and also small-disc spacings, usually only 30/1000 in. In open separators when disc spacings of this order of magnitude are employed, only extremely low-viscosity liquids may be treated, as the pressure drop between discs from friction due to viscosity becomes the primary factor (*1*).

An example of the effect of viscosity has been found in the field of vegetable-oil processing. During the water degumming of soybean oil, phosphatides or commercial lecithin are precipitated from the oil by hydration. The gums can be separated continuously from the oil by centrifugal separators to give an extremely viscous product (*2*).

When open-disc-type separators are employed, a gum product usually is obtained which when analyzed contains 65% acetone insoluble (gums) and 35% free oil on a dry basis (*3*). Any attempt to concentrate to a much higher gum content, and thereby less oil, usually resulted in plugging the separator bowl with viscous, hard gums after a short period of operation. With the Hermetic pressure separator on the same process in a commercial plant, gums of 80% acetone insoluble and only 20% oil on a dry basis are produced. The operating inlet pressure to the centrifuge is generally 100 lb./sq.in. and is primarily utilized to overcome the pressure drop due to friction from the viscous gum discharge (*4*). Because of the pressure in the separator bowl, the bowl does not become plugged by the high viscosity material. As shown, the increased efficiency of the Hermetic separator on this process results in a reduction of the free oil from 35% down to 20% or a decrease of 43%.

In another vegetable oil process, namely soda ash refining, the Hermetic separators when replacing the open-type-disc centrifuges have shown similar savings in free oil content in the soap. The increased efficiency of the Hermetic pressure separator is apparent when reductions in free oil content of soap and gums range from 30 to 50%, when compared to the open-disc-type separator.

The Hermetic separator with its back-pressure control valve on the light liquid discharge gives a feature long desired in centrifuges. The back-pressure valve provides a means of adjusting the zone of separation between the light and heavy phases while the separator is operating. In the conventional open separator, the zone is varied by means of discharge rings located at the top of the bowl. In order to adjust the zone, the

separator has to be stopped and the ring replaced with one of a different diameter. The Hermetic separator easily accomplishes this change in zone diameter by means of a simple calibrated valve located at the light phase outlet and can be varied while operating. An increase in back pressure on the outlet fluid moves the zone outward; a decrease in pressure moves the zone in, thereby accomplishing the same purpose as discharge rings.

When one operates an open separator, the selection of the proper discharge ring is of utmost importance. When low viscosity liquids are being separated such as oil and water, the discharge ring necessary to give the desired neutral zone or balance circle may be calculated from the following formula (*5*).

$$D_B = \left(\frac{d_H^2 - \rho_R d_L^2}{1 - \rho_R} \right)^{1/2}$$

where

D_B = diameter of the balance circle or zone of separation, millimeters

d_H = I.D. of discharge ring (heavy liquid discharge diameter)

d_L = diameter of light liquid discharge

ρ_R = ratio of light liquid density to that of the heavy.

The same zone may be obtained in the Hermetic separator by applying back pressure on the light phase outlet. In a similar manner the necessary back pressure may be calculated. By the use of the balance circle formula, the diameter of the zone of separation may be calculated at zero back pressure. The pressure for the zone at zero back pressure and the pressure for the separating zone desired is then calculated by using the equation for hydraulic pressure within a revolving bowl. Actually, the change in pressure required to move the zone from one diameter to another may be calculated more directly by equating the two and solving for ΔP, thus

$$\Delta P = 1.98 \times 10^{-10}(D_2^2 - D_1^2)(\rho_H - \rho_L)N^2 \qquad (1)$$

where

ΔP = back pressure on the light liquid outlet

D_2 = desired balance circle diameter, millimeters

D_1 = calculated balance circle diameter at zero back pressure

N = bowl speed, rev./min.

ρ_H and ρ_L = densities of the heavy and the light liquid respectively.

Due to the many advantages associated with this closed-pressure construction, the Hermetic separator has been utilized widely in the industrial field. Figure 3 illustrates a conventional open-disc-type centrifuge and, for comparison, illustrates the Hermetic pressure separator. Both units are of equal capacity. The Hermetic separator operates as a part of the piping system, as the feed inlet; the high-speed revolving bowl and the outlets are all under operating pressure and form a completely closed continuous unit. Since the centrifuge including the separator bowl operates under pressure, the problem of cleaning has been vastly simplified. It is now possible to back-flush the separator bowl by injecting water, a detergent solution, or a solvent into the light phase outlet and pressure-flush the discs and bowl wall. The flush solution enters at the center outlet and flushes downward off each disc and out the heavy phase outlet. In this manner the bowl may be cleaned in a few minutes without stopping or dismantling the separator. By comparison the open separator had to be stopped, the covers removed, and the bowl opened for a thorough manual washing operation. There are not only the time- and labor-saving advantages with the back-flush cleaning but also a gain in productive capacity due to less downtime.

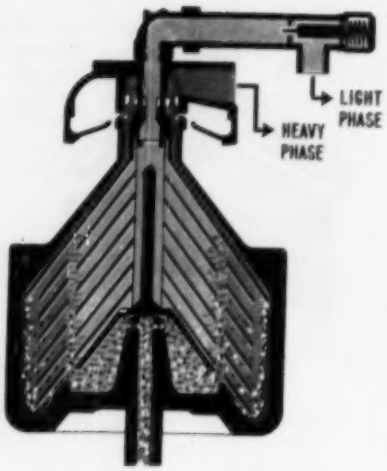

Fig. 2. Basic features of Hermetic separator.

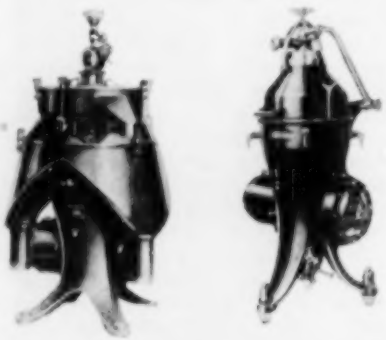

Fig. 3. A conventional open-disc-type centrifuge compared with the Hermetic separator.

One of the first fields of the industrial application of the separator was the vegetable oil industry. Owing to the high efficiency of the Hermetic separator, the normal operation of refining and degumming became more efficient and resulted in higher oil yields for the processor. Since the Hermetic centrifuge operates with pressure within the centrifugal bowl, the more viscous soap and gums obtained by the higher efficiency can be discharged easily. It was found that a new approach to soda ash refining was now possible, in that a soda ash solution could be reacted with the oil and separated without the usual dehydration or gas-removal step. Due to the operating pressure on the system, carbon dioxide gas was not given off during the reaction, and separation could take place under pressure without gasification.

Because of the closed pressurized bowl, the Hermetic separator does not aerate material when entering the separator or when discharging. It is found that certain industrial oils, which are readily emulsified when agitated, can be separated from their reaction products in the Hermetic separator whereas in the open separator, separation was impossible.

Inflammable solvents, such as alcohols, light hydrocarbons, and the like can be separated safely and economically with the Hermetic separator under pressure. Such materials as viscous cellulose acetate dissolved in solvent, can be clarified and due to the extreme viscosity of such substances, at least 150 lb./sq.in. are required to overcome frictional pressure drops in the separator bowl. An advantage of operating under these pressures is the lack of solvent loss due to flashing.

Corrosive substances can be handled more advantageously, as aeration, a definite factor in most corrosion, is now eliminated. This lack of aeration, coupled with the new noncorrosive metals on the present-day market offer many new uses for centrifugal separation.

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Presented at A.I.Ch.E. meeting, Louisville, Kentucky.

NEW MILITARY SERVICE REGULATIONS GIVE ENGINEERS POSSIBLE RESERVE STATUS

President signs Executive Orders implementing Public Law 305 . . . EJC Panel meeting hears Hershey, Dargusch explain how technologists may get into Ready and Standby Reserves, eliminating lengthy service.

If you—or men in your employ—are 1-A with the draft board and believe deferment is unlikely, the steps which can be taken to shorten the period of necessary active military training to 3-6 months are outlined in the following digest of the new Executive Orders pertaining to technologists and scientists:

(The following is C.E.P.'s digested version of the orders. For details, consult an official copy, or *Engineering & Scientific Manpower Newsletter*, No. 88, 1-18-56, published by Engineers Joint Council, 29 W. 39 St., New York 18, N. Y.)

Executive Order 10650—Selection of persons with critical skills for the Ready Reserve.

Section 1680.1—*Authority of local boards.*

(a) Local boards are authorized to so select for the Ready Reserve registrants meeting conditions described below. Selectees enlist in a three to six months active duty training program.

(b) Local boards and appeal boards shall be guided by the then current lists of critical occupations issued by the Sec. of Labor, and of essential activities issued by the Sec. of Commerce, as modified by the Dir. Office Defense Mobilization. List as of 1-6-56 included.

Critical Occupations

Engineer draftsman, design.

Engineer, professional (all branches) ("Professional" meaning B.S. degree as minimum).

Teacher, college and vocational (critical occupations only).

Critical Activities

3. *Ordnance.* Production and maintenance of weapons (including nuclear weapons and guided missiles) and component parts.

6. *Production of chemical and allied products.* Production of materials specifically used in propellants for launched or guided missiles, aircraft, armament rockets, and similar weapons, as well as the processing of the materials into propellants, exclusive of conventional fuels. Production of high temperature resins and other chemicals used specifically in the production of launched or guided missiles, aircraft, armament rockets, and similar weapons.

7. *Water & sewerage systems, operation of.*

9. *Educational services.* Colleges and vocational schools . . .

10. *Research & development services.* Basic and applied research, exploration and development projects, including process development, of direct concern to the national health, safety, or interest.

Section 1680.2—*Request by registrant.*

(a) Any registrant who believes he has the qualifications described below, and who is class 1-A may, if an appeal is not pending in his case and the period during which an appeal may be taken has expired, file a written request with his local board that he be selected for enlistment in a unit of the Ready Reserve.

(b) The request filed by the registrant shall be accompanied by (1) a certificate of the registrant and his employer to the effect that the registrant has a critical skill which is being utilized in a critical defense-supporting industry or in a research activity affecting national defense, (2) evidence that the registrant has demonstrated by his academic or employment record, or both, that he has the capacity for and gives promise of performing the duties of the occupation requiring such skill with a high degree of competence, productivity, or creativity,

(*Continued on page 58*)

With the cold war forcing a continuing race for technological superiority, the latest phase of east-west tension is concentrated on who will achieve intercontinental missiles first. Last month the U.S. took a major step toward recognizing the need to free skilled technologists and scientists from lengthy military assignments unrelated to their specialized abilities and training. The President, on January 6th, signed two Executive Orders which, for the first time in the nation's history, actually spell out the procedures by which gifted young engineers and scientists may be kept on the job as civilians.

Having nothing to do with the regular induction or occupational deferment policies and procedures (which are admittedly taking fewer and fewer simply because current military needs are less), the new regulations take over when the man is 1-A, and his appeal period has run out. Thus their major effect will be insurance to industry and educational institutions should the cold war heat-up and induction quotas rise.

Chief disadvantage of the new regulations is that the truly gifted, badly needed person still has to be away from employment for a three-to-six month period of military field training. Many persons having great concern for our national security, including leaders in the engineering professions, feel that this represents a gamble our nation can ill afford.

To quote General Dargusch, Asst. Director for Manpower of ODM, "In dealing with manpower and other mobilization problems, we should remember that the course of the government must have the general approval of our people." In this light, we of the engineering professions may very well feel that we have come a long way with these new regulations.

Advantages of the regulations are several. A practical one is that once request for permission to enlist in a unit of the Ready Reserve is received by the local (draft) board, all action on processing for induction is stopped. Teaching is recognized as a critical occupation. While many phases of the chemical process industries' functions are not rated on the current lists as occupations worthy of keeping one from induction, *research and development* activities are regarded in a broader sense. Thus, if a man with a B.S. in chemical engineering meets certain aptitude and employment requirements and can prove his work has to do with the extension and/or improvement of processing technology, he may well be on safe ground.

At Engineers Joint Council panel discussion (NYC, January 26) on "Reserve Forces Act of 1955," A. W. Davison (Member A.I.Ch.E.), chairman of E.J.C.'s Engineering Manpower Commission, E. G. Bailey (Member A.S.M.E.), and Brig. Gen. Carlton S. Dargusch, asst. director for manpower, Office of Defense Mobilization.

Also at EJC panel meeting, attended by nearly 500 industrialists and educators, Major Gen. Lewis B. Hershey, director of Selective Service System, answering questions.

TIME TO PLAN YOUR FIRM'S ENTRY INTO NUCLEAR FUEL PROCESSING

New AEC policy encourages private industry to get in nuclear fuel processing by opening information channels, underwriting, to a certain extent, the cost of initial operation.

Concrete proposals will be accepted in from 12 to 18 months.

Two practical policies are at the heart of the new program to foster a private chemical nuclear fuel processing industry.

1) AEC will make available its knowledge and experience in the technology of chemical processing to any interested firm.

2) Limited amounts of certain irradiated fuel materials from AEC reactors will be offered to private processing companies.

The first part of the program got off to a flying start at the recent Idaho Falls meeting (see below).

The second part is to help industry get started by underwriting the plants that are going to be needed in what is the largest area opened up to the chemical industry by AEC, but it cannot be hurried. A large capital investment will be involved, prior to a well-defined pattern of anticipated return.

Proposals—And Evaluation

AEC will invite proposals some 12 to 18 months from now from firms interested in the program. The companies will be expected to present their proposals for design, construction and operation of chemical processing plants capable of processing one or more of the fuel types to be employed in projected licensed power reactors, plus limited quantities of AEC irradiated materials. If a firm does not propose to process any AEC material a contract proposal will not be necessary, but a license to construct and operate will be needed from AEC.

Evaluation of the proposals made by industry will be based on certain general criteria. Advancement of the art will include the economics of the proposed plant, its versatility, and the development program to be conducted before and after plant start-up. Prices for processing AEC fuels will be evaluated against all other proposals, and against the cost of performing the same services in AEC facilities, to determine fair value. At present AEC considers that a rough, somewhat arbitrary, price target is about ½ to 1 mill/kwh. Other factors being equal, AEC will show some preference for plants with early start-up dates.

Since efficient and economical waste disposal is one of the principal long-range goals of the whole chemical separations development program, the manner in which this problem will be handled is a major consideration.

Concrete Evidence

Finally, AEC asks concrete evidence that the firm making the proposal can make satisfactory arrangements to process fuels from private reactors (no proposal will be considered which does not involve processing fuel from at least one licensed power reactor), and that assurance can be given that the project will not be abandoned.

On the basis of its evaluation, AEC may select one or more of the proposals, or may reject all if none seems satisfactory.

A 4% inventory charge will be in effect on AEC material from the time it is diverted from AEC channels until it is returned, except under special conditions. It is possible that fuels from military reactors will be available for private processing.

As a definite policy, responsibility for disposal of radioactive wastes is completely on the shoulders of the private firm, even if the facility should be located on AEC property.

Although still being studied pending final issuance, the general policy on patents involved is that AEC waives its rights to inventions or discoveries made as a result of access to Confidential-Restricted data, and its rights to all inventions and discoveries made as a result of access to Secret Restricted Data, except that in the latter case AEC maintains an irrevocable, royalty-free, nonexclusive license for use by the Government.

All in all, the new program is a major forward step in the building of a chemical fuel processing industry in this country.

IDAHO FALLS MEETING INITIATES AEC INFORMATION POLICY

Power Reactor Fuel Processing Symposium, January 18-20, details technology to industry. Unclassified gist of classified program on access permit basis, presented to representatives of some 100 industrial firms*:

AEC Policy, *Davis & Robinson*, AEC.
Canadian Fuel Processing, *Campbell*, A. E. of Canada.
Basic Processing Principles, *Lawroski & Levenson*, Argonne.
Present Facilities, *(a) Buckham*, Phillips, *(b) Platt*, Hanford.
Fuel Cooling and Storage, *Ullman & Arnold*, ORNL.
Fuel Shipping Costs, *Ayers*, Phillips.
Fuel Throughput, *Slansky*, Phillips.
Fuel Composition, *McVey*, Phillips.
Conversion of Solvent Extraction Product to Metal, *Runion*, National Lead.
Fission Products Compared to Other Sources of Radiation Power, *Manowitz*, Brookhaven.
Fission Product Processing, *Rupp*, ORNL.
Recovery of Zirconium & Niobium, *Consiglio*, Knolls.
Waste Handling Methods and Costs in Solvent Extraction Processes, *Rodger*, Argonne.
High Enrichment Fuels, *Warzel*, Phillips.
Low Enrichment and Blanket Materials, *Platt*, Hanford.
New Fuel Processing Procedures for Solvent Extraction, *Blanco*, ORNL.
Headend, Tailend, and Solvent Extraction, *Alter & Davidson*, Knolls.
Conversion of Nitrate Salts to Fluoride, *Rodger*, Argonne.
Improved Waste Treating Methods, *Burgus & Grimmett*, Phillips.
Homogeneous Fuel Processing, *Unger*, ORNL.
Fluoride Volatility Processes, *Vogel*, Argonne.
Pyrometallurgical Processing, *Feder*, Argonne.
Liquid Metal Extraction, *Doane*, Ames.
Fused Salt Extraction and Plutonium Volatility, *Motta & Mattern*, North American.
Oxidative Slagging, *Feder*, Argonne.
Liquid Metal Fuel Reactor Processing, *Manowitz & Dwyer*, Brookhaven.
Fast Reactor Processing Problem, *Stanford*, Atomic Power Devel. Assoc.
Electrorefining & Halide Volatility Processes, *Niedrach*, Knolls.
Idealized Single Purpose Separations Plant, *Ludlow*, Hanford.
Multipurpose Reactor Fuel Processing Plant, *Ullman*, ORNL.
Supporting Analytical Facilities, *Browns*, Hanford.
Summary of Meeting, *Stevenson*, Phillips.

* Alco Prod., Allied Chem., A.M.F., American-Standard, Anaconda, Atlantic Refining, Atomic Power Devl. Assoc., B. & W., Baker & Co., J. T. Baker, Batelle, Bethlehem, Blaw-Knox, Chem. Assoc., Chrysler, Cook Electric, Crane, Day & Zimmermann, Daystrom, Dorr-Oliver, Dow, DuPont, Food Machinery, Foote, Ford, Foster Wheeler, GE, General Dynamics, Goodrich, Gray Chemical, Hercules, Ionics, Kaiser Eng., Kerr McGee Oil, Koppers, Leeds & Northrup, Lithium Corp., A. D. Little, Lummus, Metals & Controls, Minneapolis-Honeywell, Monsanto, National Lead, National Research, North American Aviation, Nuclear Devel. Corp., R. M. Parsons, Pennsalt, Pfaudler, Pioneer Service & Eng., Spencer Chemical, Standard Oil, Stanford Research, Stearns-Roger, Stone & Webster, Sylvania, Union Carbide, U. S. Rubber, U. S. Steel, Vitro, Westinghouse, and others including 17 utilities.

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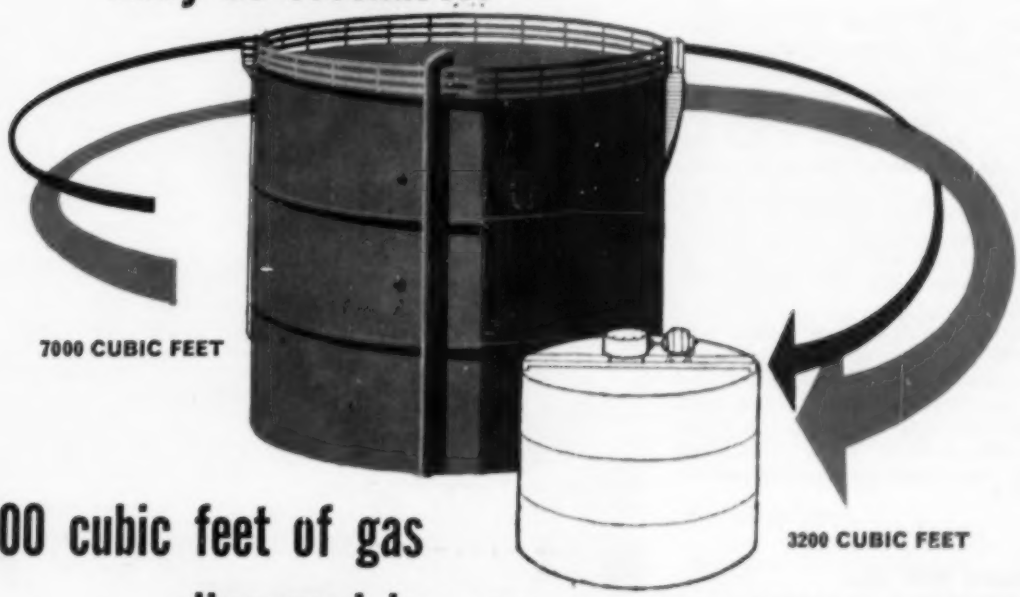

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Turbos can solve your agitation problems, whether your business is petroleum processing, chemicals, pharmaceuticals or minerals beneficiation. Turbo's built-in ruggedness that provides continuous 24-hour heavy-duty service assures you of "headache-free" production and lower costs in the long run.

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SWEDISH PROCESS USED IN NEW SHALE OIL PILOT PLANT

A new pilot plant installation for the production of shale oil by the Swedish Aspeco process is now in the works.

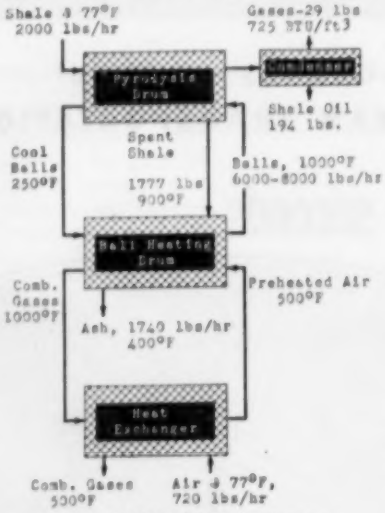
Under a $250,000 initial contract, Denver Research Institute will construct a 24 ton/day pilot plant for Oil Shale Corp., Beverly Hills, Cal., to process Colorado oil shale by the Aspeco process developed by Aspegren and Co., Stockholm, and licensed to Oil Shale Corp.

Many advantages are claimed for the Swedish process, among them being a high throughput rate, and an off-gas of high B.t.u. value suitable for pipeline transmission.

The Aspeco process (see flow sheet) consists of two horizontal, rotating kilns, one of which acts as a retort for heating raw shale to pyrolysis temperatures, and the other which acts as a heat exchanger and combustion furnace for burning off carbon from spent shale. In each kiln, properly sized crushed shale flows *countercurrent* to closely-sized steel balls. Heat transfer thus occurs through solids-solids contact, the ball material being the heat transfer medium.

In the "pyrolysis drum" heated balls (1,000° F.) and cold crushed shale enter opposite ends of the kiln and flow in countercurrent contact. The spent shale, containing residual carbon, leaves the kiln at about 900° F., the cooled balls exit from the opposite end at 250° F.

These two streams are recontacted, again in countercurrent fashion, in the combustion kiln (ball heating drum). The spent shale, containing 4% carbon, entering at 900° F., the cooled balls at 250° F. Air is introduced and the spent



Flow chart of Swedish shale-oil process.

carbon burned off the shale. The balls are thus reheated and discharged again at 1,000° F. for recycling to the pyrolysis kiln. If required, a side-stream of oil-denuded off-gases from the upper kiln may be used to supplement the ball-heating requirements in the lower kiln. A gas-fed ball heating tower is provided for start up.

NEW PROCESS FOR PICKLE LIQUOR PROBLEM

Seven major steel companies join Blaw-Knox in attack on the treatment of waste pickling liquors with new semi-commercial plant.

The perennial problem of treating and disposing of waste pickling liquors from steel operations may have a practical solution soon when results are in from the building and operation of a demonstration plant using a new process.

The plant, to be engineered, constructed and operated by Blaw-Knox's Chemical Plants Division, is co-sponsored by Jones and Laughlin, National Steel, Pittsburgh Steel, Republic Steel, U. S. Steel, Wheeling Steel, and Youngstown Sheet and Tube.

A semi-commercial unit, rated at 650 tons of sulfuric acid per year, the plant will be built at Republic's Niles, O., site, will process spent acids from the company's works there. Crux of the operation is the new Blaw-Knox Ruthner process designed to regenerate pickling solutions.

New Process—Positive Answer

A great deal of research has been conducted on the disposal and treatment of pickle liquor, present volume of which is now estimated at more than 600 million gallons per year in the U. S.

The current major method of treatment is by neutralization of the acid content with alkalis, discharging the

(*Continued on page 78*)

AWARD FOR BEST PRESENTATION AT DETROIT

John E. Powers, now at Univ. of Oklahoma, won the prize for the best presentation of a paper at the Detroit meeting with his extemporaneous talk on the Separation of Liquids by Thermal Diffusion. Speaking without notes, Powers gave a clear presentation of a most difficult subject in a light, humorous vein, using many slides of excellent quality.

Presented by a Subcommittee of the Program Committee, headed by J. Louis York, the award is made on the basis of clarity in relation to difficulty, ease of presentation, knowledge of subject, how the speaker handles the questioning session, general presentation, naturalness, use of aids to understanding.

Powers filled the bill very nearly to perfection in the opinion of the subcommittee, which had 2 or 3 men listening to each talk.

Members of sponsoring companies, the A.I.Ch.E. Research Committee, and the universities undertaking the experimental work, met at North Carolina State College in November to hear the committee and its researchers report to the sponsors on the progress of the research project on Tray Efficiencies in Distillation Columns.

VERSATILITY

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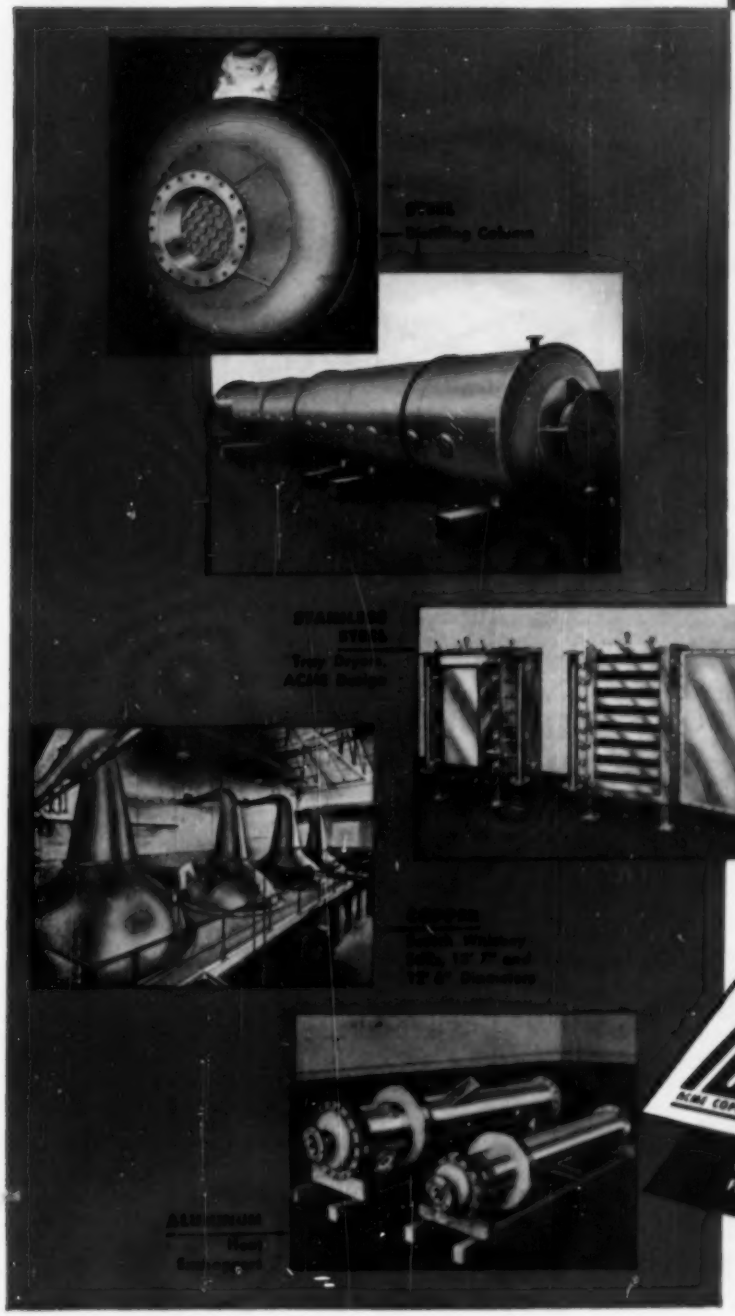
* FABRICATION



Leading Process Industries have come to depend on Acme for more efficient equipment for virtually any purpose. Acme versatility has paid dividends to many processors in time and effort saved, in greater economy of operation and more productive yields of high quality products.

The illustrations shown here are but a few from thousands of diverse units in current, successful use all over the world.

When planning a replacement or expansion program, consult Acme first!

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DESIGN AND FABRICATION IN ALL FERROUS AND NON-FERROUS METALS

J-M 85% Magnesia is lightweight . . . easy for workmen to install half-sections on this 10" steam line. Insulation work at the Grace Chemical plant was performed by Young Sales Corporation of St. Louis. Engineering and construction was directed by Foster Wheeler Corporation of New York.

Your Btu's and dollars go further when you specify **Johns-Manville 85% Magnesia**

. . . the choice of insulation engineers at Grace Chemical's new Memphis plant

INDUSTRY'S LONG-TIME standard for temperatures to 600F is still your best insulation buy. For J-M 85% Magnesia provides high insulating value, easy application, long life, initial low cost and minimum maintenance. That's why insulation engineers consistently specify J-M 85% Magnesia for modern installations like Grace Chemical's new anhydrous ammonia-urea plant. That's why it will pay you to specify J-M 85% Magnesia for your new plant or modernization program.

To assure you maximum value from your insulation dollar, Johns-Manville gives you complete drawing-board-to-job-site service. You get expert recommendations by the world's most experienced insulation engineers . . . plus expert installation by authorized J-M Insulation Contractors. Write today for further information on J-M 85% Magnesia and Johns-Manville's unmatched facilities to solve your insulation problems. Address Johns-Manville Box 60, New York 16, N.Y. In Canada, Port Credit, Ontario.

J-M 85% Magnesia also comes in block form. Here you see it being applied to a vertical drum at a New Jersey petroleum refinery.

Johns-Manville *first-in* **INSULATION**

MATERIALS · ENGINEERING · APPLICATION

The New Orleans Recipe:

blend rich cultural experience with full technical program

J. T. Hogan and J. Pominski | Southern Regional Research Labs.

Traditionally known as "the city that care forgot," unique New Orleans plays host for the third time in less than 16 years to an A.I.Ch.E. National Meeting, May 6-9.

What is the attraction of New Orleans? Simply this—the engineer can travel the country from one end to the other and never come to another New Orleans. No other city in the U.S. is like it, no other city can match its heritage of four cultures, its striking contrasts, or its myriad pleasures. A city both old and new, ancient and modern, it is a center of business, and a center of unique pleasure.

If it is the past that fascinates you, New Orleans holds the history of French, Spanish, American, and Creole. Here was the center of France in America, *La Nouvelle Orleans, Le Petit Paris.* Here still are the stately homes and history of the Spaniards. Here is where Andrew Jackson defeated the British and Jean LaFitte became a legend. And here is where one of the few completely American cultures developed in the Creole life and in the music of the jazz bands still playing loud and fast in the city's night spots.

Paris in America

General opinion has it that the engineer would have to go to Paris itself to begin to match the food, drink and *joie de vivre* of New Orleans.

Down in the French Quarter, the *Vieux Carre,* or old square, are the old French restaurants that have given the city its reputation as a gourmet's paradise. Antoine's, old, mellow, is known throughout the world for its 150 years of French cuisine, its quaint antique gas chandeliers used both for heat and light. You'll want to try the ***huitres en coquille a la Rockefeller*** (oysters Rockefeller to we foreigners), and *pompano en papillote,* both invented here and sent all over the world. At Arnauds on Bienville St. you'll get just about any French or Creole dish from shrimps Arnaud to their special *crepes suzette.* Down on Bourbon St. at Galatoires the specialty is crab meat, all types in ways you've never seen before, all hand-picked, perfect. If the food isn't quite enough at Diamond Jimmy Moran's La Louisiana on Iberville St., you can look at the fabulous building itself, once the mansion of the merchant prince Zacharie. If these are not enough, try Brennan's Vieux Carre, Bienville and Bourbon Sts., Broussard's with its open courtyard dining room, Josefs also on Bourbon.

All of these and a lot more are within easy walking distance of the Roosevelt Hotel, your headquarters while here.

After dinner, and a cup or two of New Orleans deservedly famous "black-drip" (French style coffee without which life would certainly cease in New Orleans), it is time for a little "night life." If it's night clubs you like, go down to the corner of St. Louis and Bourbon Sts. and you'll find both Stormy's Casino Royale and Prima's 500 Club. For a combination of night life and history try LaFitte's Blacksmith Restaurant and Bar on Bourbon St. which is the original location where the LaFitte brothers posed as blacksmiths to cover up their real trade—piracy and smuggling.

Certainly you won't want to skip at least one trip to a "Dixieland" jazz spot, here in the home of Dixieland. Try the Sho-Bar on Bourbon, or the Famous Door Bar, on the same street. And you just have to drop in at the Old Absinthe Bar, also on Bourbon, which has been serving its absinthe frappes since 1798, features Papa Celestin's Band.

Of course the city boasts a fine orchestra, opera, theaters, and all the other entertainment and cultural opportunities of a major city.

Whether your taste runs to night club or symphony, if you are adventurous you'll be in the French Market at the arrival of dawn, where everyone from society matron to truck driver sits on stools and drinks coffee shoulder to shoulder, just as they do every night in Paris' famous market, *Les Halles.*

At Every Corner—History

Since the adventurous French-Canadian Jean Baptiste Le Moyne, Sieur de Bienville, selected the site of New Orleans in 1718, history has marked literally every point of New Orleans.

In the world famous French Quarter lying along the Mississippi below Canal

(*Continued on page 56*)

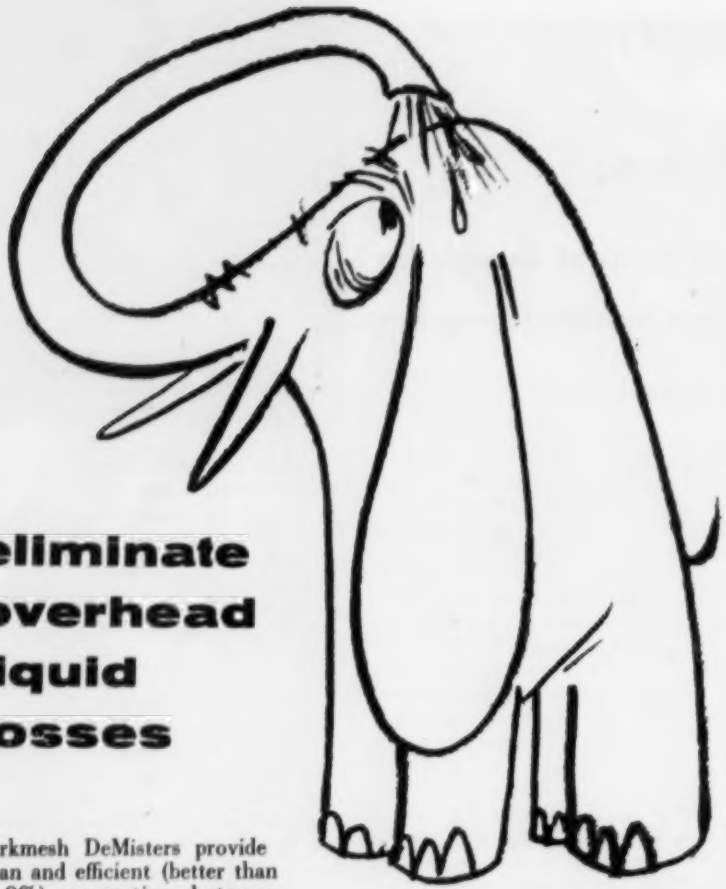
NEWLY ADDED PROGRAM FEATURE: Panel on How to Write Better

Better reports can mean better understanding with the people upstairs, or even occasionally breaking into print in the national magazines. To help you write better, or find out how to give help to engineers in your employ, a special symposium will be held in connection with the New Orleans meeting.

Under the chairmanship of E. W. Kilgren (Stanolind), panelists will include H. J. Tichy, (Hunter College), author of *C.E.P.*'s series "Engineers Can Write Better," (a reprint best-seller); Dennis Murphy, a full time instructor in better writing on the staff of Service Pipe Line, will talk on "what management can do"; and *C.E.P.* Editor John Mellecker on "what editors expect." Unannounced as yet is the speaker who will talk on "what management *expects.*"

Late word on C. W. Humphrey's (Shell Chemical) symposium on "Foreign Developments & Their Effect on the U. S. Chemical Industry" assures there will be a speaker on "selling chemicals in world competition," another on "effect of foreign processes," and one on "commercializing our technology abroad—other than selling."

Other program elements are described in Future Meetings on page 98.



eliminate overhead liquid losses

Yorkmesh DeMisters provide clean and efficient (better than 99.9%) separation between liquid and vapor with virtually no pressure drop. Easily installed into new or existing equipment, York wiremesh DeMister pads provide the most effective means for recovering valuable liquids entrained in gases or vapors, and by permitting operation at higher than normal velocities, leads to increased production from existing equipment. The unique operating principle, shown below, involves miles of wire knitted into a mesh pad that lets clean vapor through, but knocks out entrained liquid and tosses it back. In one instance, a scrubbed gas stream at 475 psig carried off 0.5 to 1.5 lbs. of triethylene glycol per MMCF even after passage through a vane type mist extractor. Because of inadequate liquid recovery, the vane type extractor was replaced by a stainless steel Yorkmesh DeMister at a total cost of $317.00, resulting in a recovery of 4.9 gallons of triethylene glycol per day, which amortized the entire DeMister pad installation in 29 days. It will pay you to investigate the advantages that Yorkmesh DeMisters can bring. Write for Bulletin 17 which will put further facts at your fingertips.

POSITIVE SEPARATION MEANS NO OVERHEAD LIQUID LOSS

Liquid droplets entrained in the vapor stream impinge on the extensive wire mesh surfaces. The fine droplets coalesce, the liquids drain free and clean vapor passes overhead.

Yorkmesh Demisters provide clean separation between liquid and vapor in: Vacuum towers • Distillation Equipment • Gas Absorbers • Scrubbers • Evaporators Knock-Out Drums • Steam Drums

YORK

OTTO H. YORK CO. INC.
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NEW ORLEANS

(Continued from page 55)

Street, you can walk down Royal Street (*Rue Royale*), once the "Main Street" of the French city, and pass under the ancient overhanging balconies, the ironwork so famous to the city, endless rows of curio, perfume and antique shops, and meet a point of historical interest every few steps. There's the Merchants Exchange, built about a century ago; the old Mortgage Office (1826) one of the best examples of Greco-Roman classical architecture in the city; the Old Bank of Louisiana, a most distinctive example of Creole style decoration; The Patio Royal and the Brulatour residence, one of the finest structures left in the Vieux Carre; the world famous outdoor restaurant, Court of the Two Sisters, with its strong flavor of Paris; the Spanish Courtyard where beautiful winding staircases connect the various balconies at different levels; Patti's Courtyard with its tropical vegetation and memories of opera's immortal Adelina Patti; and the city's "first skyscraper" (1811). . On Bourbon Street there's the home of the great Confederate statesman, Judah P. Benjamin. On Dauphine St., Audubon's Home. On Toulouse St., the wonderful Court of the Two Lions. On Orleans St., the Orleans Ballroom of ante-bellum days. On Dumaine, Madame John's Legacy (1726) oldest building in the Mississippi Valley.

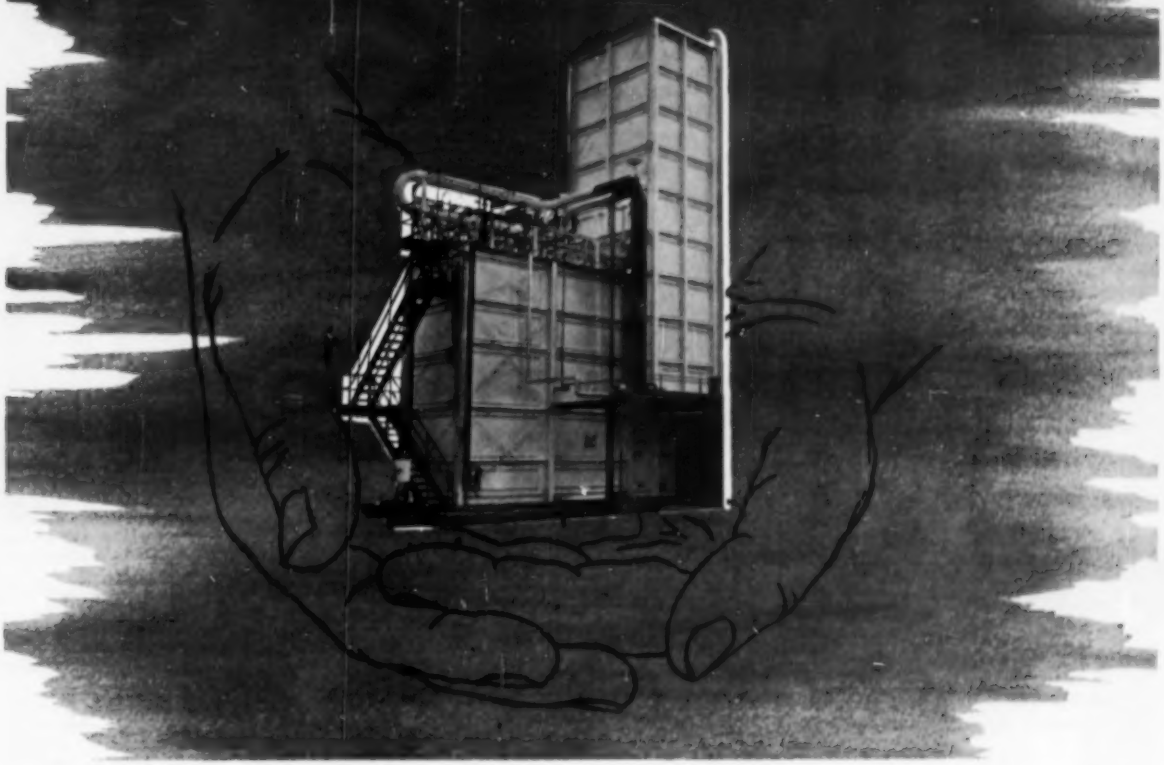
At the heart of the French Quarter is Jackson Square (Place d'Armes) with its fine statue of Jackson, the elegant and old St. Louis Cathedral, the Pontalba Buildings—two huge red-brick buildings built in 1849 by the Baroness de Pontalbe, full of long "galleries" (balconies) and ironwork—and the Cabildo, ancient seat of Spanish rule and scene of transfer of Louisiana from France to the United States.

There is as much outside the Quarter as inside. In the so-called Garden District, south of Canal St. where Americans settled after the Purchase, the houses are large, spacious, full of white columns and typical Greek Revival plantation architecture, covered with magnolias, oleanders and azaleas.

There are the outlying plantations from the pre-Civil War days, and the famous night ride on the Mississippi River boat with nightly dancing. There's Lake Pontchartrain where 1,750 acres have been reclaimed from this salt-water arm of the Gulf for residential areas, still leaving the Lake and its boating, fishing, swimming. There are dueling oaks and spanish moss, the bayous and outdoor art shows.

The March issue of C.E.P. will make suggestions for budgeting your time. Details of the Program will be included.

An Air Products "ON-LOCATION" GENERATOR keeps your OXYGEN-NITROGEN supply always in your hands



If your processes require oxygen or nitrogen in volume, your own "on-location" generator can be a tremendously profitable investment. With the free air for raw material, it can substantially reduce the cost of your end product and eliminate all uncertainty regarding your oxygen or nitrogen supply.

We are prepared to design and build for your requirements:
Large Capacity Tonnage Generators, regardless of size, purity, or cycle, with liquid pumps

or

"Packaged" High Purity Generators, producing high purity oxygen and nitrogen simultaneously —delivered safely under pressure by Air Products patented liquid pumps.

Make this oxygen-nitrogen source a member of your production family and save money. Consult us for comparison of costs.

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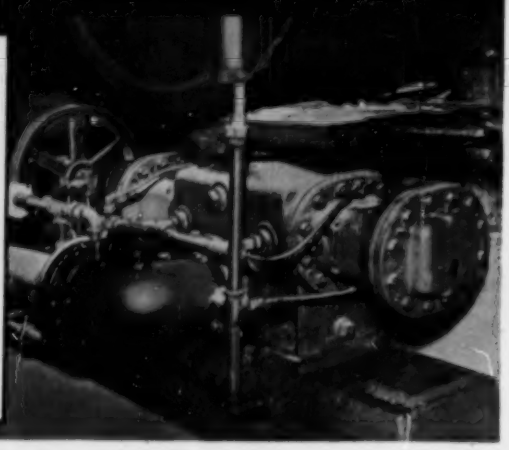
HIGH VOLUMES?

ABRASIVE MATERIALS?

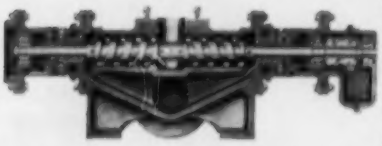
Solve your Heavy-Duty Pumping Problems with

Sier-Bath SCREW PUMPS



This Sier-Bath Screw Pump is handling gum base with a viscosity of 300,000 SSU at 128°C., delivering 6 gpm. at 250 rpm. It is an external gear and bearing, steam jacketed, hopper type, operated by a 7½ hp. motor arranged with jackshafts and pulleys. Two pumps have been operating for 8 years with minimum maintenance at L. A. Dreyfus Co., South Plainfield, N. J.

Sier-Bath SCREW PUMPS



External Gear and Bearing Bracket Type for non-lubricating liquids and semi-liquids

Internal Gear and Bearing Type for lubricating liquids and semi-liquids

Sier-Bath Screw Pumps maintain high volumetric efficiency because "Dual-Controlled" precision rotor design prevents rotor-to-rotor or rotor-to-casing contact—provides a continuous flow without pulsation, hammering or vibration . . . without strains, misalignment and wear on rotors, shafts, bearings and gears.

Result: Dependable, uninterrupted pumping service—less downtime—less maintenance—easier servicing—longer pump life—lower overall pumping costs.

Capacities from 1 to 1,000 gpm.; viscosities from 32 SSU to 1,000,000 SSU; discharge to 1,000 psi. for viscous liquids, 200 psi. for water and light oils. Horizontal or vertical construction. Corrosion resistant alloys, special bodies, stuffing boxes and bearings for special needs. Call your Sier-Bath representative or write Sier-Bath Gear & Pump Co., Inc., 9272 Hudson Blvd., North Bergen, N. J.

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50th Anniversary | Mfrs. of Precision Gears, Rotary Pumps, Flexible Gear Couplings | Member A.G.M.A.

MILITARY SERVICE

(*Continued from page 49*)

and (3) a written statement of the registrant that after completion of his three to six months active duty, he intends to return to his former employment or to enter employment in a critical defense supporting industry or in a research activity affecting national defense utilizating his critical skill.

Section 1680.3—*Action by Local Board.*

(a) Upon receipt of request of the registrant, the local board shall suspend any further processing in his case pending consideration of his request, except that if the registrant has not been physically examined, this be done.

(c) If the registrant is physically acceptable, the local board shall refer his request to the appropriate State Advisory Committee on Scientific, Engineering and Specialized Personnel, and other groups or agencies as may be appropriate.

(d) After receipt of recommendations from such Committee or groups, the local board shall approve or disapprove of the registrant's request, notifying the registrant and his employer by letter.

Section 1680.4—*Appeals.*

(a) The registrant may appeal the determination of the local board, with the appeal board or the President. The time for appeal shall begin to run from the date of the mailing to the registrant by the local board of the notice of its determination.

(b) Outcome of the appeal shall be transmitted by the local board in a letter to the registrant and his employer.

Section 1680.5—*Selection and enlistment.*

(a) Registrant selected for Ready Reserve shall enlist in a unit within 30 days after notice of his selection is mailed by the local board, or within a longer period if granted by the local board.

Section 1680.6—*Resumption of processing of registrant.*

(a) If the registrant does not enlist within the 30-day period, the local board shall process the registrant for induction in the normal manner.

Section 1690.7—*Reporting Discontinuance of employment.*

(a) After completing three to six months active duty period, registrant must keep his local board informed as to his mailing address, occupation and employment.

(b) If after completing training registrant does not return to employment in any critical defense-supporting industry or in any research activity affecting national defense, the local board shall so advise the appropriate office of the Armed Forces.

Executive Order 10651—Screening of the Ready Reserve (for transfer to Standby Reserve).

4. There shall be transferred to the Standby Reserve, in such numbers as are in excess of the requirements of the Ready Reserve, those members of the Ready Reserve who are principally engaged or employed in critical civilian occupations which are on the List of Critical Occupations for Screening the Ready Reserve issued by the Sec. of Labor. No person shall be transferred hereunder (a) who posseses a critical military skill as determined by the Sec. of Defense (and the Sec. of the Treasury with respect to the Coast Guard), or (b) who volunteers to remain in the Ready Reserve.

8. Any member of the Standby Reserve who has not completed his obligated period of military service in the Ready Reserve may be transferred to the Ready Reserve, whenever reason for his transfer to the Standby Reserve no longer exists.

Artist's Conception

Artist's Conception

CURRENT CHEMICAL PROJECTS

Shown above are just a few of the current Lummus chemical projects.

A Lummus-designed anhydrous ammonia and ammonium sulfate plants, and a Monsanto-designed sulfuric acid plant under construction for Gonzalez Chemical Industries, Inc., at Guanica, Puerto Rico.

B 30,000,000 lb/yr vinyl acetate plant engineered and constructed by Lummus for Air Reduction Chemical Company to come on stream at Calvert City in early 1956.

C First commercial installation in this country for manufacture of high pressure acetylene derivatives engineered and constructed by Lummus for General Aniline & Film Corporation to begin operations at Calvert City in late 1955.

D Phenol-Acetone plant designed, engineered and constructed for Progil-Electrochimie at Pont de Claix, France in 1955.

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LUMMUS

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OTHER CURRENT LUMMUS CHEMICAL PROJECTS

1 60-ton/day anhydrous ammonia plant being engineered and constructed for Westvaco Chlor-Alkali Division, Food Machinery & Chemical Corporation.

2 Carthage Hydrocol, now owned by Stanolind Oil & Gas Co., being redesigned and reconstructed by Lummus for manufacture of synthetic fuel and chemical raw materials from natural gas.

3 Phthalic anhydride plant for Pittsburgh Coke & Chemical Company to be built at Neville Island, Pa.

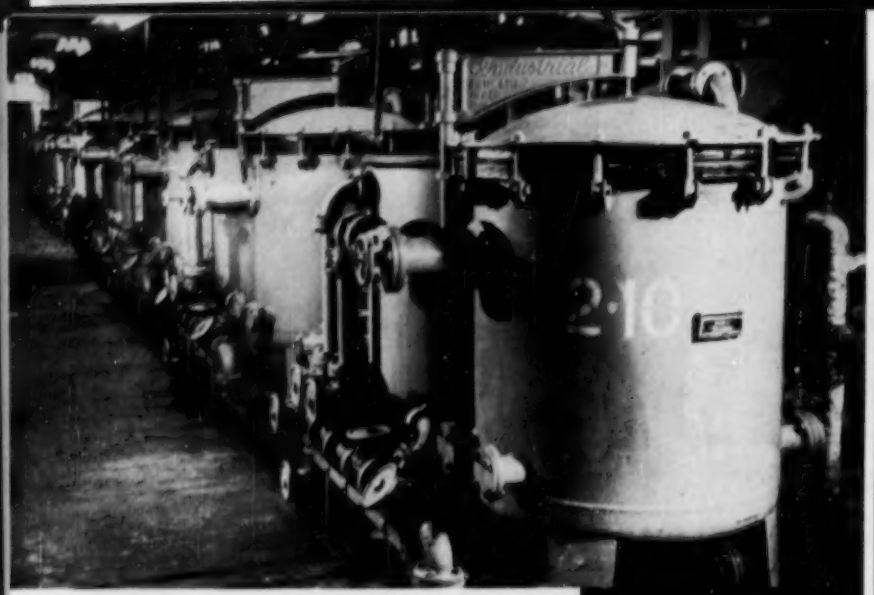
4 Lummus-designed ammonia plant for St. Paul Ammonia Products, Inc., to be built at Pine Bend, Minnesota.

5 Epon Resin units for Shell Chemical Corporation at Houston, Texas.

6 Bisphenol unit for Shell Chemical Corporation at Houston, Texas.

7 Tetramer, Cumene and Phenol-Acetone units for Societe des Chimiques des Derives du Petrole at Antwerp, Belgium.

8 Sulfuric Acid plant for Inland Chemicals Canada Limited at Fort Saskatchewan, Alberta.



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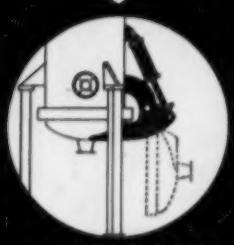
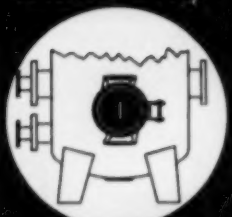


RECOVERING LARGE VOLUMES OF SOLIDS



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Fission products from nuclear piles may, through chemical engineering, become an important source of auxiliary electric energy through the development of a nuclear "battery" which translates radiation energy

Direct conversion of nuclear radiation into electricity has recently attracted considerable attention, particularly during the past year with the increasing interest in peaceful uses of atomic energy. It appears that the immediate interest lies in the possible application of such a process to produce simple, compact, and long-life power sources. However only small amounts of power are feasible at the present time.

The grand total of power available from radioisotopes is limited by the supply of fission products produced mainly as by-products of nuclear reactors. At present, it would appear that they should be considered as a possible auxiliary source of considerable magnitude, with a possible maximum roughly equivalent to that produced by batteries at the present time.

Types of Radiation

The types of radiation which are being worked on may be classified into two categories: (1) charged radiation and (2) uncharged radiation.

Examples of charged radiation are: electrons or beta rays, alpha particles, ions, and fission particles. Examples of uncharged radiation are: X-rays, gamma rays, neutrons, and light (also may be included if it is produced by some nuclear process).

Methods of Conversion

The processes of direct conversion may be classified into four categories:

1. Direct charging methods. These are usable only with charged radiation and involve the simple collection of charged carriers by an electrode to create a voltage.

A type of direct charging device studied by RCA consists of three principal parts; a radioactive source, a dielectric film, and a metal collector. A unidirectional flow of current takes place through the film which is thin enough to pass beta particles but acts as an insulator for other forms of current. This is perhaps the simplest type of direct charging device but it is subject to the same limitations as the first type. It can produce several thousand volts, but the current and the impedance depend upon the amount of radioactive material used; in fact all direct charging methods suffer this same limita-

Based on a paper presented at the Geneva International Conference on the Peaceful Uses of Atomic Energy.

directly into electric power. The total output of fission products by 1965 may provide enough potential raw material to supply as much auxiliary power as is presently produced by batteries, 2 million watts/yr.

ATOMIC BATTERIES await low-cost materials

E. G. Linder, P. Rappaport, J. J. Loferski | Radio Corporation of America, RCA Laboratories, Princeton, N. J.

tion. They should become more feasible commercially as fission products become cheaper and more plentiful.

2. Contact potential methods. These may utilize both types of radiation, and operate by the use of contact potential fields to separate charges and produce currents.

The basic principle of the contact potential method is represented by two electrodes of dissimilar metals between which there is enclosed an atmosphere of gas, for example, argon. Radiation having sufficient energy to ionize the gas will produce carrier pairs. These will be acted upon by the field because of the contact potential difference of the metal surfaces, the positive ions flowing in one direction, and the negative electrons in the opposite. This produces an electric current which may do useful work. This particular device has an especially low efficiency owing mainly to the low-absorption coefficient of gases for radioactive radiation, and the high ionization energy for gases (about 30 ev.). The efficiency may be somewhat improved by using low-energy radiation or gas under pressure.

3. Thermocouple methods. Either type of radiation is used to generate heat by simple absorption. The heat is used to activate thermojunctions.

The thermocouple method converts radiant energy directly to heat and this in turn to electricity by means of the thermoelectric effect. If the absorption of the radiation is complete, and in practice it could be made nearly so, the efficiency of the method would be that of the thermojunction. Since efficiency increases with junction temperature difference it will in general be low for low-power inputs. With 57 and 146 curies using polonium-210 the electric power delivered was respectively 0.1 and 0.2% of the power developed as heat. Maximum power delivered was 1.8 and 9.4 mw. respectively. Solar radiation efficiencies of about 1% have been attained, and with the use of concentrating reflectors or lenses it is estimated that an efficiency of about 5% would be possible The thermocouple method is clearly a simple, rugged, and long-life process. The application of modern solid state theory and experience towards the improvement of thermocouples may prove profitable.

4. Semiconductor junction methods. Carriers are formed within the semiconductor by either type of radiation, and are separated by the internal junction field.

The semiconductor method employs a p-n junction of materials such as silicon or germanium. The device may be energized by radiation of either the charged or uncharged type. By a simple process utilizing the internal electric field of the junction the radiation energy is converted directly into electric energy.

Experimental current-voltage curves are shown in Figure 1. The output current is plotted horizontally and the voltage generated vertically. The three curves are for different silicon units.

A practical type of design that approaches efficient use of the emitted radiation is shown in Figure 2 where a layer of radioactive material is sandwiched between two p-n junctions.

The semiconductor type of device has an important characteristic which enables it to overcome two disadvantages associated with the direct charging types of devices, namely small current and high internal impedance, as pointed out previously. These disadvantages are overcome by high current multiplication in the semiconductor. In other words, each Sr-Y90 beta particle that penetrates silicon, for example, will produce on the average about 200,000 new electrons. This high-electron multiplication increases the output current by a similar factor and reduces the internal impedance by the same factor. Because of these changes in current and impedance this type of device has characteristics which are in a practical range for the operation of electronic equipment, especially transistorized equipment. With practical amounts of radioactive material it is possible to design small power units, sufficient current, and a suitable impedance for operating equipment of this type.

On the other hand, this semiconductor type of converter is subject to a significant amount of semiconductor radiation damage when it is used with radioactive material of certain types. Fortunately there appear to be remedies for this type of damage, which is a function of the particle or quantum energy of the radiation. Indications are that by the use of radioactive materials whose quantum energy of radiation does not exceed the threshold value, it should be possible to construct converters of this type the life of which is not limited by radiation damage.

Summarizing all types of power sources using radioactive material, it should be stated that there are several problems yet to be solved before such devices as enumerated in this paper can be considered practical. These problems are related to:

1. **the high cost of radioactive material**
2. **radiation shielding**
3. **radiation damage**
4. **low efficiency**

It appears that all the obstacles to a practical larger power source could be solved by the appearance of a radioactive material which was of low cost, had low quantum energy, and a long half-life. Among available isotopes nickel-63 meets all these requirements except that of cost. It emits 0.063 Mev. beta radiation, and has a half-life of 85 years, however the present A.E.C. price is $45/mc. It is to be hoped that attention will be given to this and other materials in the same category.

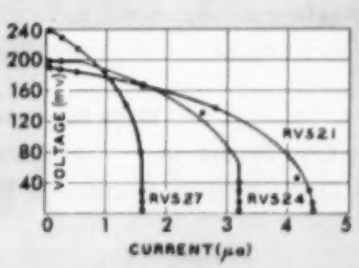

Fig. 1. Experimental current-voltage curves for silicon p-n junction converters.

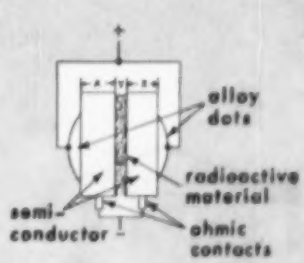

Fig. 2. Double junction arrangement for efficient use of radioactive emission.

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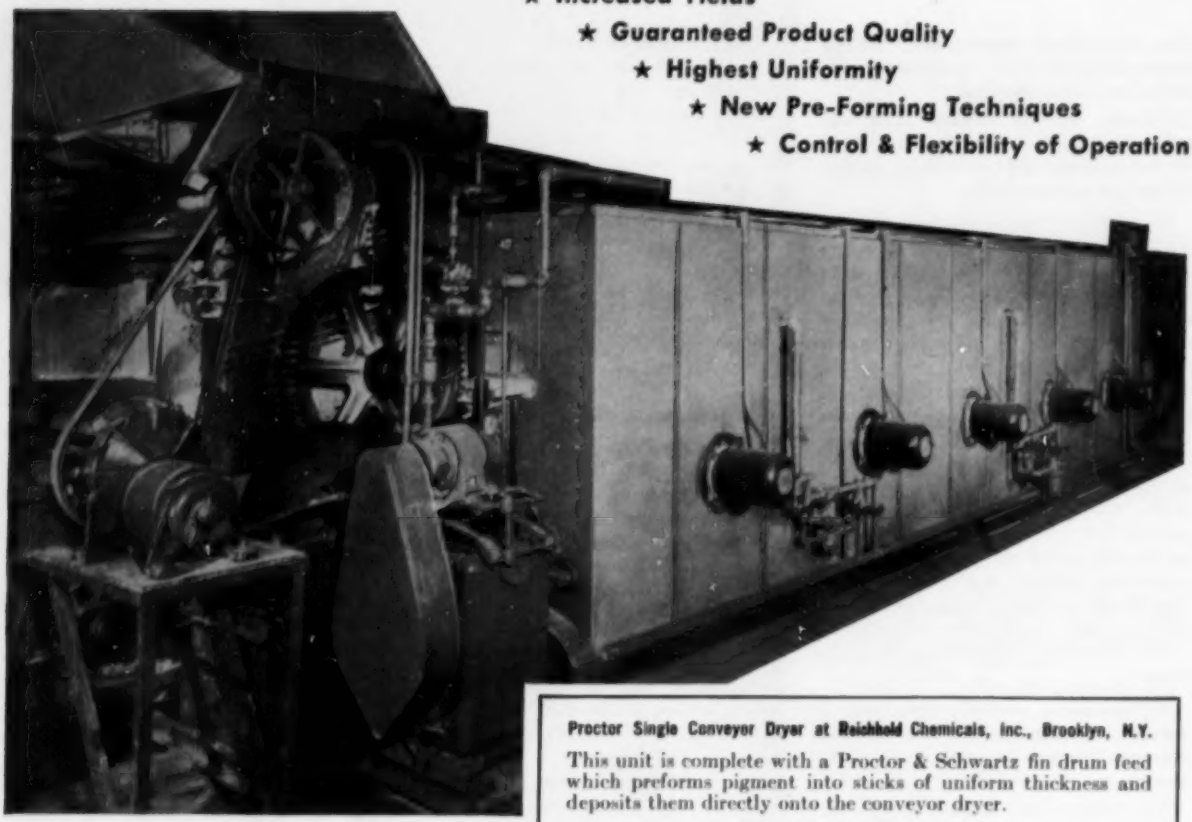

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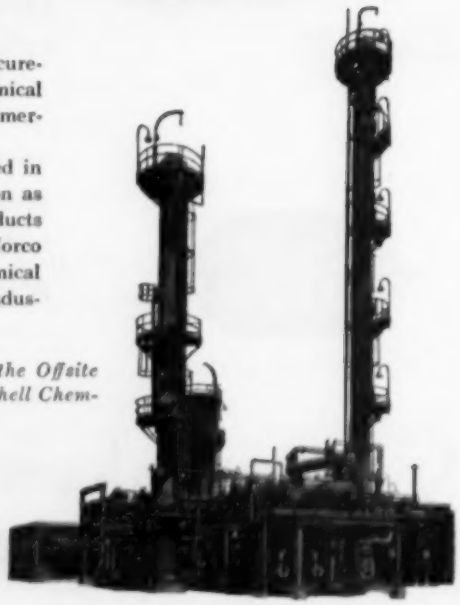

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90L	91L	91R	92TL	92BL	93BL	93R	95R	96L	97TL	97BL
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110 STATISTICAL REVIEW summarizing the production and consumption picture of the domestic zinc industry in 1955 is offered in a 13-page booklet. Comprehensive tables cover mine production, imports of slab and ore, tariff rates, consumption by grades. Detail discussion of zinc consumption for pigment production, galvanizing, and die casting. The American Zinc Institute, Inc. Circle number 110 on data post card.

(Continued on page 66)

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12L Heat Exchangers. Complete drainability & easy cleaning are asured when Aerofin type R coils are in use. Maximum heat transfer accomplished by staggering finned tubes in direction of air flow. Aerofin Corp.

13A Analog Computers. To achieve flexibility of structure & application in synthesis & analysis, planning & plotting, proving & improving investigate GAP/R modular components. George A. Philbrick Researches, Inc.

14A Pumps. Day by day advances in technology bring unsolved pumping problems. To meet this need the Worthington Corp, research & development program is continuous. They will be glad to cooperate with you on any pumping problems you may have. Available a wide standard corrosion-resistant line of pumps manufactured from Karbate impervious graphite to supplement Worthite.

16L Oxygen Analyzers. Units continuously measure process streams by an advanced magnetic principle providing direct physical measurement of the oxygen itself. Arnold O. Beckman, Inc.

17A Mixers. Designed & built for maximum efficiency Baker Perkins Inc. units are suitable for use without regard for product. Typical installation illustrated.

18A Synthetic Powder. Called Micro-Cel said to greatly improve flow of many products even under adverse storage conditions. Absorbs to 6 times its weight in water. See list of features. Johns-Manville.

20A Reducing Valve. A new Leslie Co. reducing valve called Hi-Flo said to have better than 50% greater capacity. Unique construction.

21A Heat Exchangers. A standard line in sizes from 20 to 400 sq.ft. surface of various types of construction & in single & multiple tube arrangements, available for quick delivery. Struthers Wells Corp.

22L Fittings, Tanks & Parts. Processing equipment fabricated from 11 job-proved rubber & plastics available from American Hard Rubber Co. Bulletin on comparative properties.

23A Process System. Conversion of fine particles into granular products to meet consumer demand accomplished by compacting, rolling & circle sifting. Granules are 100% —3 mesh & 100% on 10 mesh. Allis-Chalmers.

24A Conveyor Elevator. Simple adaptations of standard Stephens-Adamson Mfg. Co. products often provide low cost, efficient bulk material handling. Wide range & versatility of products permits of virtual "in stock" systems.

25A Flow Control. An electrinic, bearingless flowmeter called Pottermeter which may be easily installed in all types of piping & operates under all conditions. Accuracy ±½ of 1%. Potter Aeronautical Co.

26A Filters. Available in wide range of types units include both vacuum & pressure designs. Numerous attachments for cake dewatering & removal. Eimco Corp.

27A Catalysts. Versatility of molybdenum increases its use as a catalytic element. Functions readily as an electron acceptor or donor. Bulletin on its use in industrial applications. Climax Molybdenum Co.

28L Process Equipment. Condenser Service & Engineering Co., Inc. together with its subsidiaries are prepared to design, build & install power & process equipment & accessories. Bulletins on various types of equipment.

29A Activated Carbon. If you have a vapor phase absorption problem type BPL granular activated carbon from Pittsburgh Coke & Chemical Co. is specifically designed to solve it efficiently at low cost.

30A Pneumatic Transmitters. A complete line of these units for measuring flow, pressure, level & density. Ranges may be changed as much as 2 to 1 on standard, 10 to 1 on double weighbeam models. Republic Flow Meters Co.

31A Flaking. Controlled supercooling with Votator apparatus from Girdler Corp. said to produce better crystal structure. Continuous automatic process permits accurate control of crystallization temperature & other solidifying conditions.

DEVELOPMENTS OF THE MONTH *(Cont.)*

Coupon holder and piston lowered into lubricating cylinder and locked.

Coupon holder lubricated into position against the system pressure in pipe or tank with hand-operated pump.

Cylinder and piston assembly is then removed from base while corrosion sample remains under test.

111 CORROSION TEST SPECIMEN INSERTION & REMOVAL DEVICE. New apparatus permits injection and withdrawal of corrosion-test samples in process lines or vessels, even in high-pressure systems, without shut-down or installation of costly by-pass piping. Loss of process material, which can be toxic or noxious, is held to a minimum. Samples are subjected to actual conditions as they exist in the operating plant equipment. Accurate primary data on corrosion is thus obtained for metallic or non-metallic samples. A hydraulic cylinder operated by a hand pump serves to actuate removable pistons carrying the samples, which are inserted into the process stream through a base plate mounted to a standard welded and drilled half-coupling or tee. Upper cylinder assembly removable from permanently mounted baseplate, and transferable to other base plates for sample handling at several test points in various locations. Detailed sectional drawings in an illustrated brochure available from Willis Oil Tool Company. Circle Number 111 on data post card. See also cut-away views on next page.

(Continued on page 68)

32L Heat Exchangers. The Niagara balanced wet bulb control method of evaporative cooling or condensing automatically varies the cooling effect proportionately to the load, resulting in uniform distillation produce. Niagara Blower Co.

33A Process Pumps & Valves. Durco pumps & valves manufactured by Duriron Co., Inc. handle most materials & are available in a variety of types materials, including processing of uranium.

34A Controlled Volume Pump. With accuracy said to within ±1% the Milton Roy Co. pumps can solve your chemical metering problem. Acts as flow & ratio controllers. Pressures to 50,000 lb./sq.in.

35A Potentiometer. Said never to be "off process" the Dynalog includes a simple, radio-type variable capacitor to replace the troublesome slidewire. Results in smooth balancing. Foxboro Co.

36L Wire Cloth. Available in all corrosion-resistant metals & alloys wire screen from Cleveland Wire Cloth Mfg. Co. Available to individual specification in any size or dimension.

37A Fire Hose. Called Lite-Flex & said to be an advance in fire hose construction hose is covered with gray latex & fully rubber lined. Sizes 1½ & 2½ in., maximum lengths 100 ft. Goodall Rubber Co.

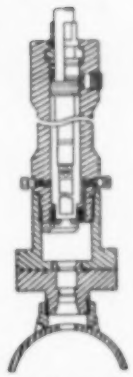
38A Stainless Steel Plate. G. O. Carlson, Inc. offer weekly stock lists on steel plate in stock. Material of high quality is produced by specialists in the field. Also available plate products, forgings, bars & sheets.

39A Grinders. Greater finenesses than may be obtained with tube or roller mills said to be accomplished by use of Sturtevant Mill Co. Micronizer. Features instant accessibility & easy cleaning.

40A Process Kettles. The right unit for every need in process service, depending on end product, capacity desired, etc. Various types agitators & mixers, heating methods & control available from Blaw-Knox Co.

41A Valves. The non-ferrous working parts in the valve from Lapp Insulator Co., Inc. insure easy working & long life in chemical atmospheres. Cutaway illustration points out features.

42A Oil Heating System. Developed by Whitlock Mfg. Co. a complete transfer oil-heating system in a compact package. Ratings 10 to 50 k.w. Arranged to conserve space, obviates leaks by welding pipe connections wherever possible.



See Developments of the Month, No. 111, on page 66. Spindle up—clapper valve closed for inserting or removing sample.

Spindle down and locked sample in position.

Sample is position—operating cylinder removed. Circle Number 111 on data post card.

Numbers without letters indicate data available as described in Data Service "Briefs." Numbers with letters refer to further data concerning products advertised in this issue. Letters indicate position of advertisement on page (if more than one on a page)—L, left; R, right; T, top; B, bottom; A indicates full page; IFC, IBC, and OBC are cover advertisements.

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25 West 45th Street
New York 36,
New York

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CHEMICAL ENGINEERING PROGRESS
25 West 45th Street
New York 36,
New York

products-(Cont.)

advertised in this issue

43A Metallic Sodium. U. S. Industrial Chemicals Co. has available a book titled "Handling Metallic Sodium" of major interest to design engineers & production men. Detailed information based on in-plant experience.

44FA Chemical Porcelain. Providing virtually universal corrosion resistance plus fast, simplified assembly excepting only against hydrofluoric acid & hot caustics are chemical porcelain piping & process units from U. S. Stoneware Co. Bulletins available.

44L Joints & Couplings. Fabricated from Teflon are Chemiseal expansion joints & flexible couplings which protect costly chemical piping & have low impact strength. Pressure tested at plant. U. S. Gasket-Belmont Packing Co.

45A Filteraids. If your need is sharp filtration to trap better than 95% bacteria & other sub-micronized solids Dicalite filteraids do that. Others give faster flow rates. There is a product for your every need. Dicalite Div., Great Lakes Carbon Corp.

46A Catalysts. A wide line of alumina based catalysts, as well as synthetic silica-alumina & other special-based catalysts available from Chemicals Div., Houdry Process Corp.

48A Process Equipment. Unequalled corrosion-resistance, immunity to thermal shock & ruggedness of mechanical design are the boast of Karbate impervious graphite equipment fabricated by National Carbon Co.

51A Mixers. If absorption of gas into liquid is a problem a Turbo mixer is suggested. Gas absorber units handle to 7,000 cu.ft./min. with proved operation. General American Transportation Corp.

53A Process Equipment. If you are planning new installations, a replacement or expansion consult Acme Coppersmithing & Machine Co. who design, engineer & fabricate versatile units.

54A Magnesia. 85% magnesia which provides high insulating value plus other features is consistently specified by insulation engineers. Available from Johns-Manville.

56L DeMisters. York wiremesh DeMister pads provide effective means for recovery of valuable liquids entrained in gases or vapors. Permit operations at higher than normal velocities. Otto H. York Co., Inc.

58L Screw Pumps. Said to maintain high volumetric efficiency because of their dual-controlled precision rotor design Sier-Bath Gear & Pump Co. units will aid in solution of your heavy-duty pumping problems.

59A Chemical Plants. When next you plan a new plant consult The Lummus Co. Specialists in plant design & construction they will undertake your project from drawing board to operation.

60L Filters. You can now solve complex filter problems by using Industrial Filter & Pump Mfg. Co. new built-to-order features. A complete filtration engineering service from fluid analysis to installation, also available.

62A Dryers. The ranges in Proctor & Schwartz, Inc. units make possible continuous conveyor drying of materials formerly dried by batch processing. Units carry performance guarantee.

63A Electrodes & Anodes. Uniformity of raw materials provides a plus factor in Great Lakes Carbon Corp. graphite electrodes, anodes, carbon brick & mold stock.

64A Petrochemicals. Fluor Corp., Ltd. are specialists in design, construction, operation of petrochemical installations.

69A Blender. Patterson-Kelley Co., Inc. products include the twin-shell as well as other blenders said to furnish maximum results. Lab models scale up accurately to production sizes.

71A Valves. For many of the process services in the pulp & paper & other industries Crane Co. nickel cast iron valves are economical. Gates on hand in sizes 2 to 18 in. Checks to 12 in. Available to 18 in. on special order.

73A Rotary Pump. A stainless steel rotary pump with unique flex-i-line design which eliminates stuffing boxes, shaft seals, gaskets & check valves. Self-priming. Venton Pump & Equipment Co.

74TL Barrier Creams. Called Kerodex this substance protects hands from industrial skin irritants. Spreads like a cream & acts like a glove. Ayerst Laboratories.

74BL Mechanical Seals. A complete reference catalog on Dura Seal the engineered mechanical seal which rotates with the shaft is available from Durametallic Corp.

76L Comparators. To aid your control crystallization, bleaching, other activities with fast, easy pH & chlorine analyses, unit from W. A. Taylor and Co. Color standards guaranteed.

77A Process Filters. Units of every type available. Process Filters, Inc. Progressive procurement plan.

78L Research Laboratories. Constructed with a view toward answering the needs of tomorrow, research or control laboratories by Wigton-Abbott Corp. Specialists in all industrial fields.

79A Horizontal Processing. A self-discharging horizontal dryer constructed by Bethlehem Foundry & Machine Co. offers solutions to many processing problems in a variety of difficult operations. Details available.

80L Filter Presses. D. R. Sperry & Co. are fabricators of a complete range of styles & sizes for every filtration need. Center or corner feed, open or closed delivery & other variations available.

81R Process Tanks. Facilities for working out complex problems in plate fabrication by experienced hands is one of the services available from Downingtown Iron Works, Inc. specialists in the field.

82L Wire Cloth. Anti-corrosion wire cloth or wire cloth parts fabricated from a variety of metals & designed to meet the most severe service conditions are the products of Newark Wire Cloth Co.

83A Process Equipment. Strippers, absorber towers, accumulator tanks & Conkey dewaterers all are aids to processing for profit. These & other products of Chicago Bridge & Iron Co. designed to meet exacting requirements.

84L Packing. Lattice braid with Teflon is only one of Garlock Packing Co's. 2,000 products. You may order as a trial quantity as little as 10 ft. Teflon core & impregnation resist all but molten alkali metals & some freons.

85A Valves. Cooper Alloy Corp. stainless steel valves are continually studied by field engineers who report findings at organized clinics. Arrangements for such a clinic in your plant made by made through Cooper's Public Relations Division.

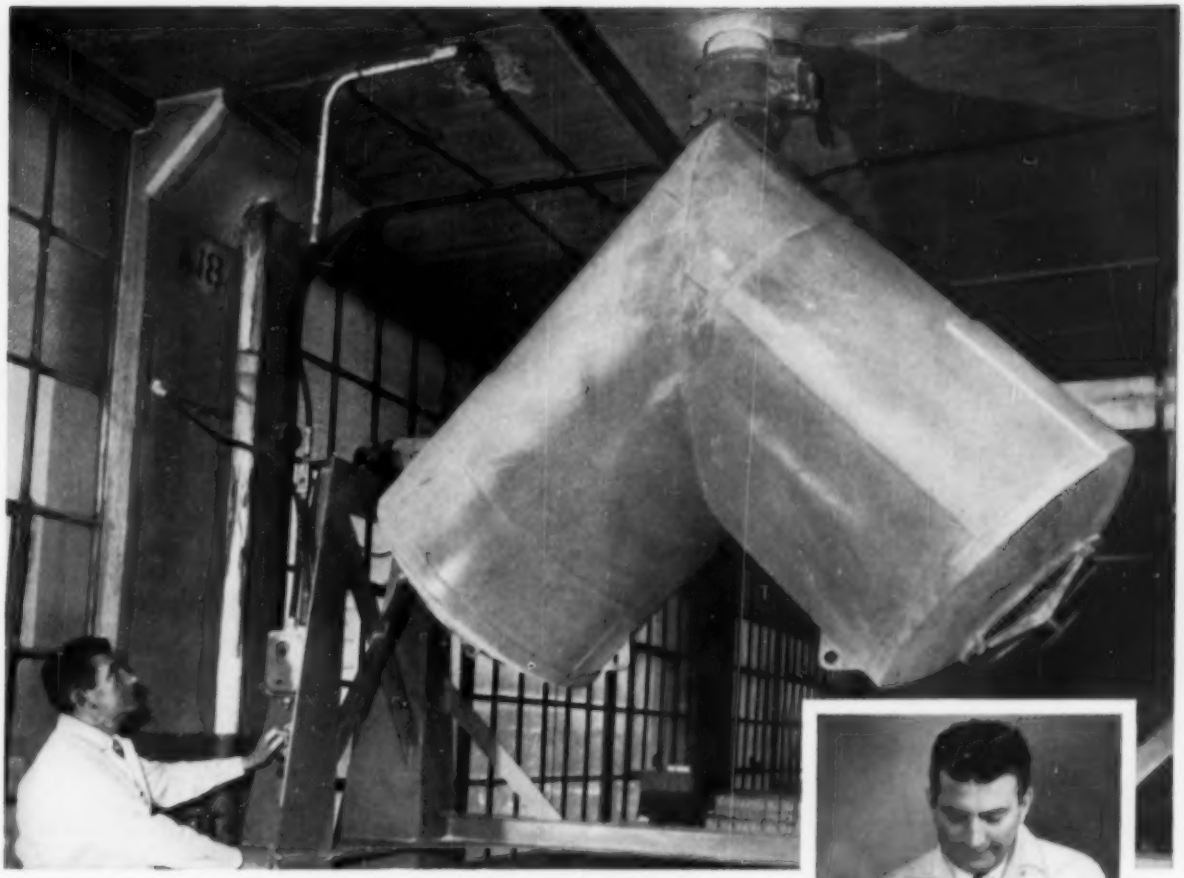
86L Castings. High-nickel castings for service where conditions of high temperature & corrosion exist are fabricated by Duraloy Co. If you wish, their metallurgist will study your particular problem.

(Continued on page 70)

DEVELOPMENTS OF THE MONTH (Cont.)

112 REACTIONS WITH PERACETIC ACID & HYDROGEN PEROXIDE. Comprehensive new 49-page compendium on epoxidation and hydroxylation with hydrogen peroxide or peracetic acid. Covers basic reaction data, equipment, safety considerations, methods of analysis, and many other phases of the use of these newer industrial chemicals. Describes fully the reactions of unsaturated olefins, both aliphatic and alicyclic. Important feature is a 9-page conversion table for rapid calculation of moles of ethylenic unsaturation, oxidant requirements, and per cent of oxirane oxygen or hydroxyl in the resultant product. Bibliography of nearly 70 references included. Becco Chemical Division, Food Machinery & Chemical Corporation. Circle number 112 on data post card.

(Continued on page 70)



This giant **p-k** twin shell blender has already blended millions of pounds of Durkee seasoning salts, loading efficiently from the floor above and discharging to the floor below. Blending, cleaning and maintenance time have been so reduced that this twin shell paid for itself in only a few months. Stewart Woodruff (right), head of Durkee's research lab, conducted the extensive tests which led to the selection of the twin-shell blender.

"Blends perfectly; virtually self-cleaning":

DURKEE SELECTS p-k BLENDER AFTER LABORATORY "PRE-TEST"

We're at Durkee Famous Foods, in Elmhurst, N. Y. . . . and you're looking at a 1000-lb. **p-k** twin shell blender which was so thoroughly pre-tested, success was assured even before it was installed!

Extra-effective blending is a must at Durkee, because physical segregation between various ingredients in Durkee's onion salt and garlic salt is a problem. That's why, when it comes to choosing a blender, there could be no guesswork.

The twin shell, along with other blenders, was put under careful scrutiny. A 4-quart **p-k** laboratory model underwent a series of tests in Durkee research labs. There, in much less than half the time needed to produce a hand sample of almost perfect theoretical value, the **p-k** twin shell, in test after test, produced identical samples. Because blending results obtained with twin shell lab models scale up accurately to production sizes, Durkee research men knew the twin shell was the "just right" blender for the job—*before* it was purchased!

To find out how you, too, can "pre-test" a **p-k** twin shell blender in your plant, lab or mill, write us today. Ask, too, for your copy of **p-k** Catalog 13. It is free for the asking, of course. **The Patterson-Kelley Co., Inc., 1720 Lackawanna Avenue, East Stroudsburg, Penna.**

PATTERSON KELLEY

Offices: 101 Park Avenue, New York 17 • Railway Exchange Building, Chicago 4 • 1700 Walnut Street, Philadelphia 3 • 96-A Huntington Avenue, Boston 16 and other principal cities

products-(Cont.)

87L Filter Press Closer. A new unit called Hydro-Lock converts manually operated filter presses to hydraulic operation in less than an hour. Enables repeated closing to uniform pressure. Blach Industries, Inc.

87R Viscometer. An 8-speed viscometer from Brookfield Engineering Laboratories, Inc. is portable & permits of easy measurement of viscosity of any fluid. Readings to 1/5 of 1% with viscosity of 1 to 32 million centipoises.

88TL Filter Media. If your filter process is giving trouble because of slurry containing slimy fines, gelatineous or minute particles there is an Eaton-Dikeman Co. filter paper to fill your need. Ask for a Filtration Analysis Report.

88BL PVC Fittings & Flanges. From Tube Turns Plastics, Inc. unplasticized PVC fittings made by the Hendry process. Said to be superior to parts made by conventional methods. Resist both internal & external corrosion.

89L Process Tanks. Whatever your process & regardless of size or type there is an Alsop Engineering Corp. filter, mixer, or storage & mixing tank suitable for your use. Recommendations upon request.

89R Steam Jet Ejectors. Designed to handle corrosive vapors & maintain vacuum, durable Elliott type H ejectors. Made of Haveg, Permanite or other synthetic resin material. Elliott Co.

90L Filtration. Production of pure, sanitary water of better quality than ground water may be accomplished by use of the Ranney method available from Water Supplies, Inc. Entirely eliminates costly filter plants.

91L Speed Reducers. For high horsepower reduction with heavy shock loads, Herringbone reducers from Philadelphia Gear Works, Inc. Available in single, double & triple reductions, wide range of capacities & ratios.

Developments of the Month *(Continued)*

114 ENGINEERING DATA ON FORGED STAINLESS AND ALLOY STEEL FITTINGS is shown in a new 8-page bulletin illustrated with cross-sections and dimension diagrams, by Watson-Stillman Fittings Division, H. K. Porter Co., Inc. Screw-end and socket-weld types are listed in seven alloys, including three stainless steels, Monel, and three chrome-molybdenum alloys. Standard classes in the screw-end type are 2,000, 3,000, & 6,000 lbs.; welding fittings include the schedules 40, 80, 160, and double extra heavy. Besides complete dimensions and weights of fittings, the bulletin shows specifications, compositions, and mechanical test data for all listed alloys. For copies of this bulletin, circle number 114 on the data card.

(Continued on page 72)

91R Tantalum. Recommended for certain processes including most acid solutions & corrosive gases or vapors except HF, strong alkalis or substances containing free SO_3, tantalum is suggested by Fansteel Metallurgical Corp. when in spite of initial cost it is the cheapest material available.

92TL Tubing. Wilmad Glass Co. Inc. manufactures precision bore tubing for use in barometers, bearings, viscometers & many other applications. Available in various shapes & sizes in Pyrex & Vycor brand & most electronic glasses.

92BL Pumps. Eco Engineering Co. All-Chem rotary pumps are available from stock in capacities 1 to 10 gal./min., pressures to 150 lb./sq.in. Impellers of Teflon, Neoprene or Formica.

93BL Rotameters. For measuring flow rate Schutte and Koerting's Safeguard units. Feature long list of plus values. Full details available in bulletin.

93R Internally Geared Motor. Called Syncrogear, motor of 5 to 10,000 rev./min., ⅓ to 30 h.p. Said to be more than a motor. Packaged assembly. U. S. Electrical Motors Inc.

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95R Drying Agent. Called Florite this economical granular drying agent offers longer service life, gives low dew point depression, & agressively resists poisoning effects. Floridin Co.

96L Air Pollution. A valuable aid to offsetting air pollution problems contained in the Bendix-Friez Aerovane system. Automatically controls actuation of equipment such as fans, blowers, etc. Bendix Aviation Corp.

97TL Gear Pumps. For solution of pumping problems in every field & of many kinds of materials investigate Schutte and Koerting gear pumps. Cooperation available on special requirements.

97BL Spray Nozzles. Properly engineered spray nozzles can help to do things better & faster. Spraying Systems Co. an authority in this field show you how & why in their catalog.

97R Car Puller. An ideal cost-saving unit for installations, large or small, requiring movement of railroad cars. One man with single unit can spot up to 6 fully loaded box cars quickly. Stephens-Adamson Mfg. Co.

98L Air Regulator-Filter. A combination regulator & filter from Ace Glass Inc. for use where clean, fine filtered air & accurate pressure regulation are desired.

99TL Filter & Filler. Two Ertel Engineering Corp. units for use in making small production efficient. Equipped with all features of high production equipment. Detailed information on request.

99BL Heat Transfer Units. From Schutte and Koerting Co. standard or special heat transfer units for service in the petroleum, power, & chemical process as well as other industries. Two- & single-pass designs.

99R Pumping. A progress report on pumping for use by chemical engineers & an invitation to consult on your own pumping problems. Aldrich Pump Co.

100TL Filter. An enclosed horizontal filter claimed to be leakproof & vaporproof, for batch or continuous operation. Cake remains in place when run is interrupted. Easily cleaned. T. Shriver & Co., Inc.

100BL Nozzles. Spray Engineering Co. manufacturers of every type of nozzle invite your attention to their complete catalog.

101L Processing Equipment. Whatever your need in the field of heat & corrosion equipment, or processing equipment, Misco Fabricators, Inc. are prepared to design & build it for you.

101R Bubble Caps. This particular item is indexed in Chemical Engineering Catalog by 26 companies. Just one example of the wealth & variety of data to be found therein. Reinhold Publishing Corp.

102L Silicone Defoamers. Production rises when foam decreases. Three available types all effective at low concentrations. Samples available. Dow Corning Corp.

102BR Piping Systems. Published by John Wiley & Sons, Inc. a book titled "Design of Piping Systems." Written by members of the staff of M. W. Kellogg Co. it covers the entire subject.

103TR Slurry Pumps. Presently in use two Nagle Pumps, Inc. 4 in. type T units in a 2-stage installation handling 600 gal./min. fly ash slurry against 400 ft. of head. Pump may be easily dismantled. For use on gritty, abusive jobs.

103BR Process Equipment. Edw. Renneburg & Sons Co. offers a complete line of dryers, ammoniators, granulators, coolers, & other equipment.

105A Research & Development Center. Men interested in scientific research are needed by the Jet Propulsion Laboratory of California Institute of Technology. See list of openings.

109TL Pyrometer. A quick-acting, light weight, accurate surface pyrometer. Features 4¾ in. direct reading dial. Five standard ranges. Pyrometer Instrument Co.

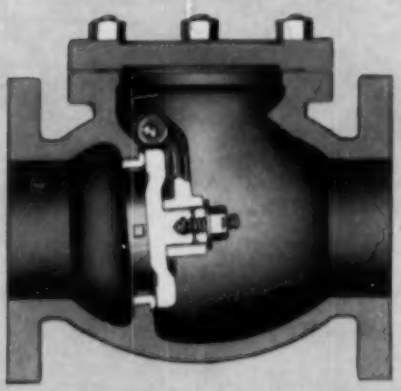
109BL Dust Sampler. Called Konisampler this unit from Joseph B. Ficklen, III employs the principle of thermal precipitation. Secures particulate matter suitable for permanent records.

(Continued on page 72)

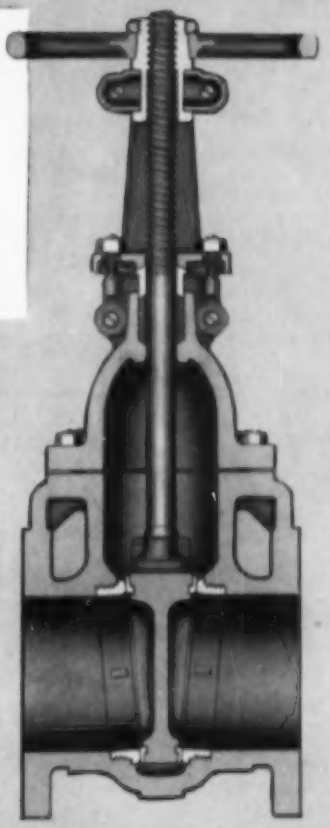
Economy Buy for Many Process Services

IN PULP AND PAPER, WOOD TREATING, CHEMICAL, PETROLEUM, ETC.

WORKING PRESSURES: GATES AND CHECKS
12 in. and smaller—200 psi W.O.G.
14 in. and larger—150 psi W.O.G.



Cross section, Check, No. 14493
Flanged ends



Cross section, Gate, No. 14477
Flanged ends

Crane Nickel Cast Iron Valves
IMMEDIATE DELIVERY from Factory Stocks

Why wait for low nickel alloy cast iron valves when you can get Crane quality—at no extra cost—immediately from factory stocks? Gates on hand in sizes: 2″—2½″—3″—4″—6″—8″—10″—12″—14″—16″—18″. Checks in all the same sizes up to 12″ incl. (14″—16″—18″ will be made to order). This delivery offer good while present stocks last.

These valves have an outstanding record in the pulp and paper industry in handling various alkaline liquors. In wood treating they're used successfully on creosote vapors and oils. They're ideal, in the petroleum industry, for handling oils containing traces of mineral acids. Crane 18-8 SMo alloy trim in these valves combines with nickel alloy body to assure tight seating and smooth, maintenance-free operation. The gates have Crane features such as: full-length disc guides . . . 2-piece ball-type gland . . . T-head disc-stem connection.

The checks feature all 18-8 SMo trim, including body ring, disc, hinge and hinge pin in sizes 2 to 12 inches. Valves 14 inches and larger have disc same as body, with 18-8 SMo disc faces.

You'll save with these valves on original cost and maintenance. Call a Crane Representative for immediate delivery! Crane Co., General Offices, Chicago 5. Branches and Wholesalers in all industrial areas.

CRANE *Since 1855*

VALVES & FITTINGS • PIPE • KITCHENS • PLUMBING • HEATING

products-(Cont.)

109R Temperature & Measurement Control. Called Xactline unit controls temperature automatically. Hand pyrometer called Xactemp for quick, accurate temperature reading. Claud S. Gordon Co.

110L Controls. A variety of controls for pressures, temperature, liquid level & other uses for indoor, outdoor & hazardous locations, all with sealed mercury contacts. Mercoid Corp.

111R Jet Vacuum Equipment. Types of equipment in the field & available from Croll-Reynolds Co., Inc. are listed in ad, plus information on the development of jet units.

IBC Heat Exchangers. High pressure heat exchanger sections form the product of Brown Fintube Co.

OBC Fluid Mixing. You neither should nor need to guess about fluid mixing. Much late information available from Mixing Equipment Co., Inc.

materials-

1 Plastolein. Now available on a commercial basis, Plastolein 9404 (triethylene glycol dipelargonate). Has value in plasticization of synthetic rubbers, as a low-temperature plasticizer it imparts other characteristics which make it an economical replacement for materials now in use. Emery Industries, Inc. Technical bulletin.

2 Lauryl Alcohols. Added to a line of higher fatty alcohols from Rohm & Haas Co. are two new ones, Dytol J-68 & 95% lauryl alcohol. As anti-foaming & emulsifying agents these materials are of interest for textile & surface-active agent applications. Also as intermediates as polymerization regulators for synthetic rubber & other uses.

3 Foam Rubber Deodorant. Deodorizing polyurethane plastics on a commercial scale has been realized with development by Witco Chemical Co. of an odor-free, more efficient emulsifier-coupler. Technical bulletin itemizes physical properties, gives data on solubility & dispersability.

4 Curing Agent. Available in experimental quantities Epon curing agent T. Principal use said to be in room temperature contact pressure laminating, in the tooling field & automobile body patch kits. Shell Chemical Corp.

5 Chemical Products. Ansul Chemical Co. have available two new bulletins. One analyzes properties of four new Ansul ethers. The other analyzes D.M.B. (dimethoxy benzene), a solid crystalline diether, & H.A. hydroxy anisole.

6 Soda Ash. From American Potash & Chemical Corp. a folder on Trona soda ash. Covers various grades, distribution & other material pertaining to industrial applications.

7 Etho-chemicals. A new booklet called Armour Etho-chemicals from Armour & Co. describes properties & applications of ethylene oxide derivatives of fatty acids, fatty amines & fatty amides. Materials have proven use in textile, cosmetics, petroleum, and other industries.

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8 Monohydric Alcohol. Abitol, a primary, monohydric alcohol, is subject of technical booklet from Hercules Powder Co. Major use is in alkyd resins. Sections on physical & chemical properties, use in alkyd resin design, applications.

9 Rubber Chemical. Formerly called Indulin 70-GR-S & now named Polypol S-70, a material from West Virginia Pulp and Paper Co. for use in semi-hard rubber compounds is covered in technical bulletin 203. Gives comparative properties of semi-hard compounds made with named material vs. the 1,500 type GR-S copolymer.

10 Organic Chlorine Compounds. A 48-page book titled "Organic Chlorine Compounds." Recently published by Carbide and Carbon Chemicals Co. Discusses applications of 18 products, their solvent properties, handling & storage. Includes data on physical properties, test methods, constant boiling mixtures, fourteen charts on physical property data.

11 Industrial Chemicals. Available from Tennessee Corp., industrial & agricultural chemicals as described in recent folder. Samples & information available.

12 Diisocyanates. Six technical bulletins cover Nacconates (diisocyanates) their properties & reactivity. Bulletin I-17, 24 pages, include generic properties, 27 basic reactions, eight pages of suggested uses. Five supplementary bulletins give specific technical data. National Aniline Div., Allied Chemical & Dye Corp.

14 Cyclohexanol. A revised technical data sheet from Monsanto Chemical Co. on cyclohexanol illustrates typical reactions such as ester formation, dehydration & oxidation to cyclohexanone & adipic acid. Major uses are in products such as cleaners, solvents, & specialized soaps.

15 Solvents & Solvent Oils. A 6-page bulletin on Picco solvents & solvent oils is available from Pennsylvania Industrial Chemical Corp. Includes charts showing typical analysis & distillation range for various grades.

16 Tertiary Amines. Known as Armeen M2HT, M2C, & M2S these amines have both their alkyl groups derived from hydrogenated tallow, coco or soya respectively. Recently made available by Armour and Co. materials are covered in a technical bulletin which treats solubility, physical properties, reactions, uses, etc.

bulletins-

20 Steel Plate Handbook. From Posey Iron Works, Inc. a loose-leaf handbook on steel plate construction. Supplies detailed data on tank sizes, codes, welding, bursting strengths & other pertinent factors.

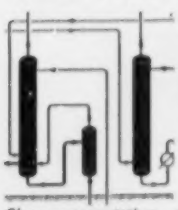
21 Dryers. Multi-colored bulletin from Silver Engineering Works, Inc. on the Parry dryer. This new process features turbulent entrainment. Controlled temperatures plus high rates of heat transfer remove surface moisture almost instantly, inherent or combined moisture in seconds.

22 Colorimetric Analysis. W. A. Taylor Co. has just released the 25th Anniversary edition of its handbook "Modern pH and Chlorine Control," incorporating the theory & practice of colorimetric analysis. This pocket-size, 100-page booklet serves as handy reference for quantitative determinations of pH, chlorine, bromine, & other special tests.

23 Metallic Stearates. The properties & uses of metallic stearates are the subject of a bulletin from Witco Chemical Co. Lists composition of 46 stearates, shows graphically the industries which employ them & gives analysis of recommended applications.

(Continued on page 74)

DEVELOPMENTS OF THE MONTH (Cont.)

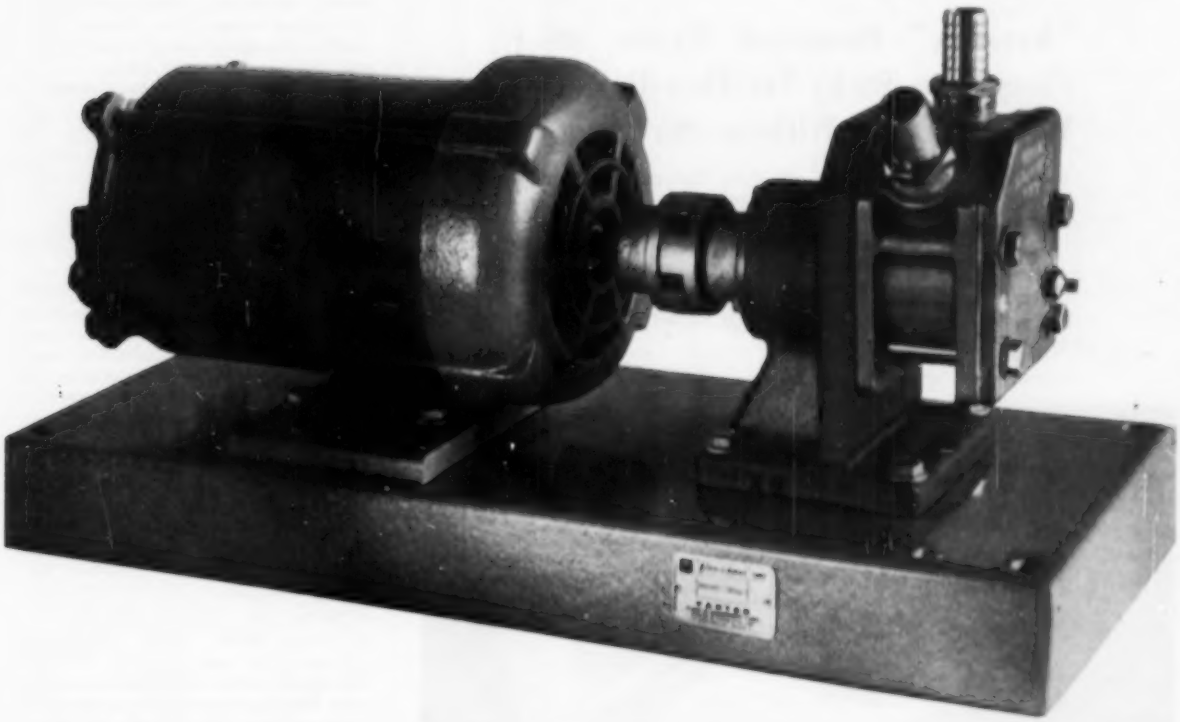


115 FLOW DIAGRAMS OF OUTSTANDING PROCESSES IN THE PETROLEUM REFINING INDUSTRY are shown in 69-page brochure by Foster Wheeler Corporation. Clear presentation of flows of charge, intermediates, and products through 41 processes, with operating data whenever available from licensor companies. Among refining methods featured are catalytic cracking, reforming, and polymerization, desulfurization, solvent naphtha fractionation, thermal cracking, and reforming, treating and sweetening, and LPG recovery. Each flow diagram is accompanied by explanatory text, and in many cases photographs of existing operating units are shown. With but three exceptions, the diagrams are factual representations of the flows in Foster Wheeler designed units. Circle Number 115 on data post card.

(Continued on page 74)

VANTON "flex-alloy" stainless steel rotary pump

the one *(and only) stainless steel rotary pump without stuffing boxes or shaft seals!*



Here is a stainless steel rotary pump that is really different! The unique "flex-i-liner" design eliminates stuffing boxes, shaft seals, gaskets or check valves. It limits fluid contact to the stainless steel housing and the durable plastic or rubber flexible liner, making the "Flex-Alloy" ideal for the toughest corrosives and abrasive slurries.

"Flex-Alloy" pumps are self priming, and their gentle pumping action permits safe handling of shear sensitive emulsions and suspensions. Pump units are available in capacity ratings from ½ to 20 gpm and can be furnished direct connected to constant or variable speed motor equipment. Vacuums up to 26" of mercury are developed.

Housings: Regularly furnished in type 316 stainless steel. Other alloys are available on request.

Liners: Available from stock in Neoprene, Buna N, gum or natural rubber, Hycar, Hypalon, Silicone, Vinyl or Compar.

Bulletin VP561 on request

VANTON
PUMP & EQUIPMENT CORP.
division of Cooper Alloy Corporation HILLSIDE, N.J.

"Kerodex" Protected Hands are Plunged in Sticky Tar Then Quickly Washed Clean Without Scrubbing.

"Kerodex" provides really effective protection against the many skin irritants encountered in industry. It spreads on like a cream but acts like a glove that is invisible yet strong and as elastic as the skin itself. Does not smear. Does not affect materials handled. Write for full information on "Kerodex"® barrier creams to Ayerst Laboratories, 22 East 40th Street, New York 16, N. Y. 5553

***A Book You Should Have on* Mechanical Sealing...**

A complete reference catalog on Dura Seal—the engineered mechanical seal that rotates with the shaft. Amply illustrated . . . specific applications . . . installation data. A fact book of real value to designers, operators and maintenance departments.

WRITE FOR DURA SEAL CATALOG NO. 455-CEP

DURAMETALLIC CORPORATION

KALAMAZOO, MICHIGAN

bulletins-(Cont.)

24 Centrifugal Pumps. A revised bulletin from Worthington Corp. presents information on single stage vertically split process pumps with capacities to 1,200 gal./min. & heads to 475 ft. Outline drawings show typical sections of various units. Chart lists other pertinent information.

25 Oscilloscopes. From Tektronix, Inc. short form catalog on cathode-ray oscilloscopes & auxiliary instruments. Units are quickly & easily converted to variety of applications by plugging in appropriate vertical preamplifier. Easy to handle & with low space requirements.

26 Plastics & Resins. New, revised, "1956 Condensed Reference File of Bakelite Plastics and Resins," offered by Bakelite Co. 12-page summary of technical data about wide range of special & general-purpose phenolic, vinyl, polyethylene, other plastics & resins, plus Krene film & sheeting.

27 Dylan Polyethylene. Just issued by Koppers Co. two technical bulletins describing in detail application of Dylan polyethylene for extrusion into various types of pipes & piping as well as application in injection molded pieces. Sections on characteristics, applications, technical service & other features.

28 Stainless Fasteners. A well illustrated 52-page stainless fastener data book is offered by Allmetal Screw Products Co., Inc. Thumb-indexed for easy reference, book contains thread & size specifications,, & availability in variety of corrosion resistant metals of 40 basic fastening devices such as screws, bolts, nuts & the like. Includes engineering data, composition, properties, weights of stainless, other tables.

29 Aluminum Alloys. Commercial aluminum alloys are the subject of a brochure from Peter A. Frasse & Co., Inc. describing in detail the general properties, fabricating characteristics, typical applications, & available size ranges of each alloy.

30 Process Plants. Design, engineering, construction & initial operation of industrial plants detailed in a 20-page catalog from Blaw-Knox Co. Industries considered are general industrial chemicals; fine chemicals & pharmaceuticals; organics, dyes & intermediates; food processing; resins & plastics, plus many others. Also considered are plant rehabilitation & modernization.

Developments of the Month *(Continued)*

116 FACT FILE ON CHLOROWAX, in the form of a new, illustrated ready-reference manual of 36 pages, lists available grades and reviews their principal fields of application. A series of tables covers typical characteristics and physical properties of this chlorinated paraffin, including compatibility, heat stability, viscosity, specific gravity, solubility, and miscibility. The booklet, expected to be of widespread interest to producers of paints, plastics, printing inks, adhesives, and rubber, is issued by Diamond Alkali Company. Circle number 116 on data post card.

(Continued on page 76)

✓ **CHECK** *your Data Service requests on the handy postcard on page 65 to*

▶ **GET** *up-to-the-minute catalogs, data sheets and bulletins on new chemical products, processes and equipment.*

31 Piping Flexibility Analysis. How processing & power piping costs may be substantially reduced both in materials, design & construction is the subject of a 12-page brochure from M. W. Kellogg Co. Gives details of general analytical method of piping flexibility analysis. Not based on approximations. Describes Kellogg's piping model test & electronic computing facilities. Feature of book is solution of a typical piping stress problem by general analytical method & model test.

32 Heat Exchangers. Complete product information on Falls Industries, Inc., two newest impervious graphite heat exchangers covered in 12-page, 2-color catalog. Cubical unit provides greatest amount of transfer service per unit of volume. Cross-Bore exchangers utilize one-piece cylindrical bundle. Same overall dimensions as standard shell & tube unit. Operating pressures 150 to 200 lb/sq.in. Constructed so that corrosives contact only graphite surfaces.

33 Packaged Turbo-Dryer. For small production such as pilot plant & experimental drying operations the packaged Turbo-Dryer from Wyssmont Co., Inc. Illustrated folder describes these small units which are said to embody same efficiency & economy features as larger models. For use in the chemical, food, pharmaceutical, plastics & processing industries.

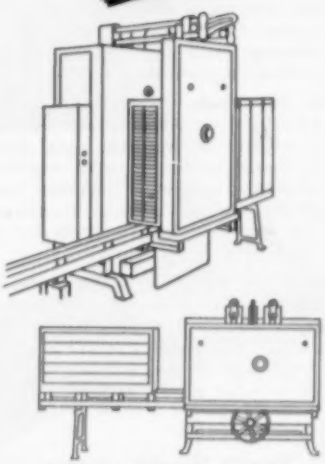
34 Liquid Level Control. In a new 8-page bulletin Foxboro Co. describes closed tank liquid level measurement & control with new type 13 LA d/p cell liquid level transmitter. Said to be essentially same as familiar force balance differential pressure flow transmitter with exception of addition of simple range suppressor spring. Balances out effect of hydrostatic pressure in piping line from high point of tank.

35 Spectrophotometer. A 4-page analysis form provides method for estimating present & potential work load on a laboratory for spectrochemical analysis. Also indicates typical analyses on near-infrared spectral region. Beckman Instruments, Inc.

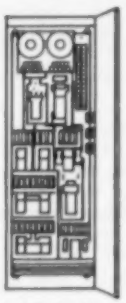
36 Controls. New 52-page catalog describes & illustrates entire line of Mercoid Corp. controls based on sealed mercury contact switches characterized by silence, non-wearing properties & immunity to dirt & corrosion. Complete reference data on types, operating ranges & specifications.

(Continued on page 76)

TRY IT automatically the TURBO WAY



Turbo High Pressure Steam and Vacuum Cabinets used for processing in bulk with trays, racks or cans. Interior capacity: 18 cubic feet.



Typical Turbo Electrical Panel unit, the heart of Turbo automatic operation and high efficiency.

Self-generating steam units. Cold water to steam in 90 seconds.

Since 1929, Turbo has been designing and building equipment for drying and steam processing:

— drying equipment so automatic and dependable that it takes the guesswork completely out of the process.

— steam processing equipment, either high or low pressure, for sterilization, food preservation, textile processing.

The same automatic, semi-automatic or manual controls . . . the same conveyor ideas, the same electrical panel controls, when combined by Turbo skill, imagination and experience, can be the solution to your process problems.

Turbo facilities are complete. Design and engineering departments . . . machine shops . . . tooling departments, all function as one to get you what you want. There's an easy way to determine just what Turbo can do for you — give us a few facts about your requirements. No obligation — the coupon is for your convenience.

TURBO MACHINE COMPANY
LANSDALE, PA.

TURBO SINCE 1929

Turbo Machine Company
ATTENTION: E. J. Berger, Vice President
Lansdale, Pa.

We'd like to discuss Turbo Engineered Processing for the following purpose:

Present processing method:

Name _____ Title _____

Company _____

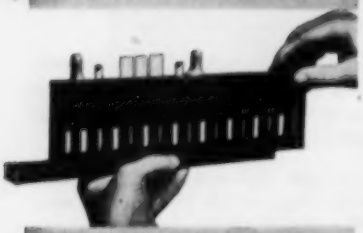
Street _____

City _____ Zone ____ State _____

TAYLOR COMPARATORS

help you control

- CRYSTALLIZATION
- BLEACHING
- PRECIPITATION
- EXTRACTION
- WASTE TREATMENT



with fast, easy
pH and CHLORINE analyses

Handy kits help you control unit operations and waste disposal with fast, accurate colorimetric analyses . . . right on the spot. By Taylor's simple visual methods, you can determine pH, chlorine, bromine, phosphate, QAC, nitrate and metal ions quantitatively in only three easy steps . . . just take your sample, add reagent and read direct after comparing with a standard. Test kits are completely portable for use by plant supervisors and foremen as well as in the laboratory.

COLOR STANDARDS GUARANTEED

Taylor liquid color standards carry an unlimited guarantee against fading . . . no danger of mechanical inaccuracy. Each complete set of standards is mounted in a lightweight, durable plastic slide . . . no single standards to handle.

CALL YOUR LABORATORY SUPPLY HOUSE for Taylor sets or write direct for FREE HANDBOOK, "Modern pH and Chlorine Control". Gives theory and application of pH control, illustrates and describes full Taylor line.

W. A. TAYLOR AND CO.
412 RODGERS FORGE RD. • BALTIMORE 4, MD.

equipment-

65 Electric Steam Boiler. Larger capacity models of the Hot Shot boiler are being introduced by Automatic Steam Products Corp. Eight models in different sizes. Units are portable & compact, fast steaming, with full pressure obtained in 20 min.

66 Ultra-Filtration. Developed by the Wheelbrator Corp. a process for super cleaning atmospheric air with industrial-type filtration equipment. Employs conventional dust collectors of tubular cloth filter type. Involves charging filter aid which precoats. Advantage lies in high cleaning efficiency & almost no maintenance expense.

67 Tube Bender. Called Exactol & introduced by Parker Appliance Co. instrument is compact, crank-operated, worm geared for manual bending to exact tolerances. Can handle annealed or ⅛H cold drawn stainless steel tubing easily. Grooves accommodate tube sizes ¼ to ¾ in. o.d. Binder insert catalog available.

68 Rotary Feeders. Recently unveiled by Prater Pulverizer Co. is a new design blow-thru rotary Airlock feeder. Design meets needs of high & low pressure systems in process industries. Applications range from fine dust removal in cyclone collectors to feeding ground products to pneumatic conveying systems.

69 Viscosity Controller. A pneumatically operated viscosity controller new with Norcross Corp. uses an air cylinder to raise a piston which draws a sample into the measuring element. Time required for piston to fall by gravity is measure of viscosity. Control station measures time of fall & opens valve to add solvent when required.

70 Shell & Tube Heater. Fabricated from Pyrex glass a shell & tube heater introduced by Corning Glass Works. Unit has capacity of 50 sq.ft. Developed to heat corrosive liquids (except hydrofluoric) in glass tubing by introducing steam into an enclosing steel jacket. Also heats coke by-product corrosive oils & liquids for steel pickling & electroplating.

Developments of the Month *(Continued)*

117 APPLICATION OF ULTRASONIC GENERATORS to many problems in the chemical process industries may be aided by publication of a new and comprehensive booklet, titled "Design of Nickel Magnetostriction Transducers," by Boyd A. Wise of Battelle Memorial Institute. Transducers are used to convert electrical input energy to mechanical output energy or vice versa. The fully-illustrated booklet summarizes all practical experiments to guide the engineer toward a workable design in exploring new fields in the utilization of sonic and ultrasonic energy. Performance limits, construction, and operation are covered in 38 pages, with charts and diagrams, and a 33-item bibliography is included. The International Nickel Company, Inc. Circle number 117 on data post card.

✓ **CHECK** *your Data Service requests on the handy postcard on page 65 to*

▶ **GET** *up-to-the-minute catalogs, data sheets and bulletins on new chemical products, processes and equipment.*

71 Thermocouple Connector System. Now a "Do-It-Yourself" unit for use in laboratory or plant. Components or complete assemblies quickly & easily assembled from standard interchangeable parts, available from stock. Plug & jack inserts fabricated in four alloys for various types of thermocouples. Marlin Mfg. Corp.

72 Tantalum Corrosion Test Kit. A tantalum corrosion test kit, convenient for use in laboratory or in process equipment, available without charge to pilot plant & research technicians. Tantalum is immune to attack by most acids (even at boiling temperatures), wet chlorine, chlorine dioxide, bromine, iodine & halogen compounds except fluorides. Fansteel Metallurgical Corp.

73 High Pressure Autoclave. Developed by High Pressure Equipment Co., Inc. a high pressure autoclave with water-cooled drive shaft. Agitator designed for all types of catalytic material from gases to solids. Pressure safety innovation is completely enclosed base. Pressures 500 to 30,000 lb./sq.in. capacities 1 liter to 20 gal. Manufactured in variety of materials.

74 Centrifugal Pumps. Norwood Works of Allis-Chalmers Mfg. Co. announce development of leakless, general purpose centrifugal pump lines, utilizing canned motor principle. Designed for handling precious or hazardous liquids where leakage cannot be permitted. Available in a fractional horsepower line including motors through 2 h.p., & an integral horsepower line also having motors through 2 h.p. Accommodate heads to 250 ft. & temperatures to 250° F. with capacities to 500 gal./min.

75 Filter Devices. New devices for increasing filter performance & convenience now available on filters built by Industrial Filter & Pump Mfg. Co. Illustrated bulletin shows cutaway drawings, lists features & applications. Filter leaves may be lifted from manifold without unbolting, bottom & top outlet leaves, has a quick opening cover, other conveniences.

76 Gearmotors & Motorgears. From Link-Belt Co. a completely new line of these units in keeping with new NEMA motor sizes which deliver more horsepower per pound. Compactness achieved through arrangement of hardened gears. Ratio changes simplified through use of but one low-speed gear set per drive size. Operating parts easily accessible. Bulletin available.

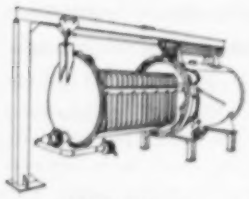
this man's plant is equipped with...

PROCESS FILTERS

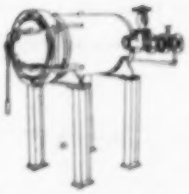
If you would like information on the efficient, trouble-free, high production Process Filters, contact Mr. Edward A. Ulrich, Vice President

VERTICAL LEAF FILTERS

VERTICAL BATCH FILTERS



HORIZONTAL LEAF FILTERS

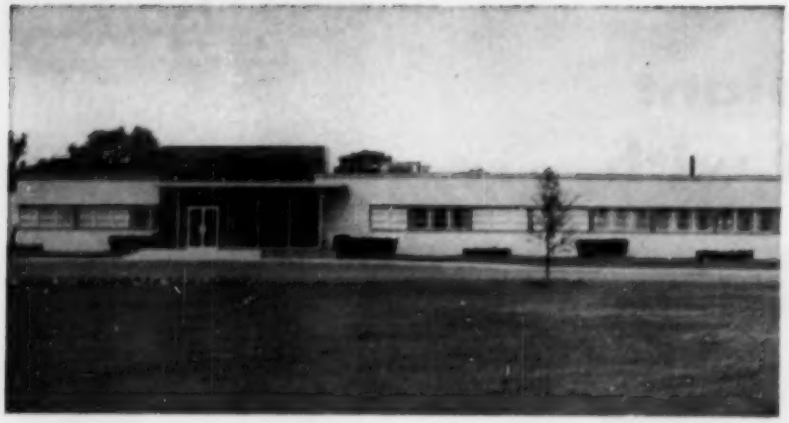


HORIZONTAL BATCH FILTERS

CARTRIDGE FILTERS

PROCESS FILTERS, INC.
1807 Elmwood Ave., Buffalo 7, N. Y.
A subsidiary of BOWSER, Inc.

Ask about the time-payment plan for capital investments.



Research Laboratories
The Norwich Pharmacal Co.
Norwich, New York

LABORATORY SAMPLE FROM

Wigton-Abbott

RESEARCH LABORATORIES — DESIGNED — ENGINEERED and Constructed to answer your needs and the competition of tomorrow

Research or Control laboratories are intricate feats of design. Everything must be planned, designed and equipped to produce utmost efficiency and successful results.

Wigton — Abbott Corporation has had long experience in creating and developing Research Laboratories in all fields of industry. A long list of satisfied clients will certify our proficiency in *Engineering* and *Construction.*

Wigton — Abbott welcomes your inquiry and the opportunity to place our experienced organization of specialists at your service.

SURVEYS, REPORTS AND PROCESS DESIGN, INDUSTRIAL DESIGN AND CONSTRUCTION, EQUIPMENT INSTALLATION

Wigton-Abbott Corporation
ENGINEERS & CONSTRUCTORS
Main Office
PLAINFIELD, N. J.
Est. 1924

PICKLE LIQUOR

(*Continued from page 52*)

sludge into lagoons where the material is dewatered. Objections to this: High cost, accumulation of large quantities of sludge presenting a difficult disposal problem.

In the Blaw-Knox Ruthner process, designed to be a completely positive answer to the problem by producing only reusable materials with no by-products, the entire sulfate equivalent of the waste liquor is regenerated as fresh sulfuric acid for reuse in pickling steel. The iron in the pickle solution is recovered as essentially pure iron oxide, and is recharged to the blast furnaces.

Basic reactions of the process were discovered by Othmar Ruthner of Vienna, extensively developed by Blaw-Knox and converted to American practices and standards.

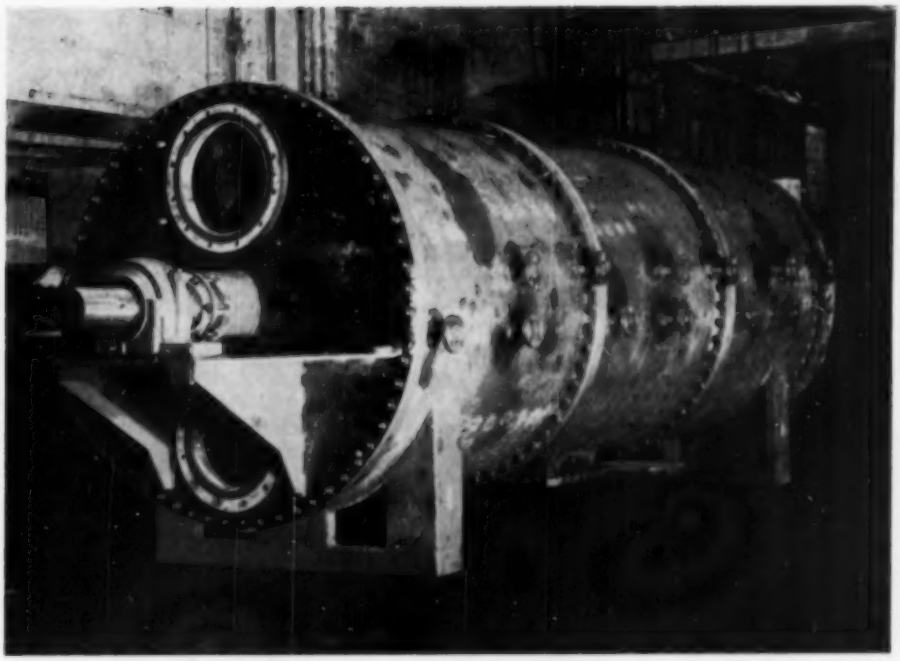
Engineers will be following the results of the demonstration plant very closely. It could be the answer to a long-standing headache.

The rapidity of growth and change in the process industries is demonstrated once again in the phenomenal expansion of Industrial Filter and Pump Manufacturing Co., Chicago, which recently broke ground on its second 50% expansion project in the last three years.

R. E. Liedberg, exec. v.p., turns ground for $500,000 expansion.

The company, a 30-year-old specialist in plating equipment, only went into a serious push for chemical equipment business in 1951 with a line of filters, heat exchangers, pumps, and waste treatment equipment. Since 1953 the company will have increased its plant size 100% when the new $500,000 expansion is on stream. The engineering staff has gone up 300% since then, the chemical engineers 400%.

Basing its growth on a line designed for adaptation to customer needs, the company is now following the policy of "completely engineered installations." □



5' Dia. x 16' Long Horizontal Dryer with spring loaded scraper agitators in place

HORIZONTAL PROCESSING

by Bethlehem

Horizontal Processing Offers These Solutions to Processing Problems:

- Continuous or Semi-continuous Operation
- Processing of High Consistency Materials
- High Heat Transfer Rate, Vigorous Mixing, and Intense Shearing
- Reasonable Power Input for Agitation
- Exposure and Renewal of Surface

For Difficult Operations Such As:

- Evaporation of Water and Solvents from Slurries, Sludges and Pastes
- Reaction Between Gases, Solids or Materials of High Consistency
- Drying of Solids
- Continuous Production of Such Products as Formic Acid and Gypsum

Agitator assembly

Bethlehem Horizontal Dryer For Sludge Operates Semi-Continously

Horizontal, mechanically agitated dryer evaporates organic liquid from ore sludge.

Thermocoil construction (cast iron with cast-in steel coils) for shell is especially useful for circulating liquid heat transfer such as molten salt or Dowtherm. Cast iron shell, machined inside, provides an even, non-galling surface for scraper agitators. Fabricated agitators of abrasion resistant steel are specially designed for obtaining high heat transfer despite caking effect of sludge drying at the wall. Agitators and entire unit constructed for ease of maintenance. Unit is self-discharging.

Call on Bethlehem's years of experience in designing and building processing equipment to solve your horizontal processing application. We have designs which may be easily adapted to your process, or we can design units tailored to fit your process.

For complete details call in one of our engineers.

1856 BETHLEHEM 1956

One Hundredth Anniversary

BETHLEHEM FOUNDRY & MACHINE CO.

Process Equipment Division

BETHLEHEM PENNSYLVANIA

SPERRY

As pioneers in the filter press field, and one of the oldest and foremost manufacturers of filtration equipment, D. R. SPERRY & CO. is well qualified to evaluate your specific filtration requirements.
Sperry *Research* has categorically filed over 60 years filtration experience from continuous field reports and laboratory tests. Sperry *Engineering* applies filtration's most advanced thinking in the development of new products and new methods for obtaining better filtration at lower cost.
Working side-by-side, Sperry *Research* and Sperry *Engineering* offer today's best source of information and equipment for tomorrow's production needs.

FILTER

A complete range of styles and sizes . . . standard or special . . . for every filtration need. With center, side, or corner feed; open or closed delivery; simple or thorough washing; jacketed plates for filtering at controlled high or low temperatures.

PRESSES

SPERRY FILTER BASES

All types . . . all sizes. Plain or punched to your specifications. Besides cotton and paper, bases are furnished in wool, synthetics, glass and woven metals.

SPERRY Closing Devices

Sperry offers the widest range of Closing Devices to match your filter design needs. Each engineered in its own way to speed production, insure safety, save labor, and increase the life of the filter cloths. Choose from nine popular models—including the new easy-to-install HANDRAULIC and the popular EHC-L Electric Closing Device—factory installed on new Sperry Filter Presses or field installed in existing presses of any make.

Send for SPERRY CATALOG

Complete with charts, tables, and diagrams to help in the operation, maintenance and selection of filtration equipment. Write for your free copy of Catalog 7-E today.

New Handraulic Closing Device

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Denver 18, Colorado

Texas Chemical Engineering Co.,
4101 San Jacinto
Houston 6, Texas

NEW PLANT, NEW PROCESS FOR HYDROGEN PEROXIDE

Predicted newsprint boom focuses attention on Solvay Process Division's new Syracuse plant which uses new chemical process.

With Canada, world's leading producer of newsprint, predicting a sharp increase in world requirements, expected to go as high as a 100% increase by 1980, the going on-stream of Solvay Division's new hydrogen peroxide plant assumes increased significance—since one major use for hydrogen peroxide is as a bleach for ground wood pulp used to make newsprint. At present Canada produces 6,180,000 tons of newsprint per year, expects an increase to 12,500,000 by 1980.

With such an increase in newsprint requirements expected, abundant hydrogen peroxide is an important factor, since it makes possible the use of ground wood pulp which, in turn, results in a more complete utilization of wood stock than other paper producing methods, contributing to conservation of forest resources.

Solvay's plant itself, a major installation, occupies an 8-acre plot in Syracuse, comprises a number of buildings for the various operations involved, including the synthesis, distillation, and purification.

New Process

Engineering and long range attention is centered more on the new process used than on the plant itself.

Initiated by Allied Chemical's Central Research Laboratory at Morristown, N. J., and perfected by a team of chemists and chemical engineers in Syracuse, the new process is chemical rather than electrolytic. Involving an oxidation reaction, the process is said to be the most advanced and efficient method developed to date for the manufacture of hydrogen peroxide.

Hydrogen requirements for the new process are supplied by Solvay's nearby chlorine plant, oxygen is obtained from the air. A thoroughly modern plant, the installation utilizes the latest devel-

opments in plastics, metals, and structural materials, makes extensive use of glass piping and glass lined equipment.

The problem of trained personnel with a new process was solved by using a prototype pilot plant both to prove the process and train the operators.

Hydrogen peroxide will be produced in both 35% and 50% grades, will be shipped in aluminum drums and tank cars.

Plant changes and additional equipment costing some $1,300,000, will be necessary at AEC's Monsanto operated Mound Laboratory because of the assignment to the laboratory of additional development and production work. □

Low-cost, Belgian developed, L'Azote process for the economical production of synthetic ammonia from coke-oven gas, refinery gas, or any other sources of hydrogen, is now available in this country.

Of primary interest to the steel industry, where enough coke-oven gas is available to produce more than 11 million tons of ammonia, the process is now in the hands of Koppers Company, Inc., as holder of the North American rights to design, construct and license plants.

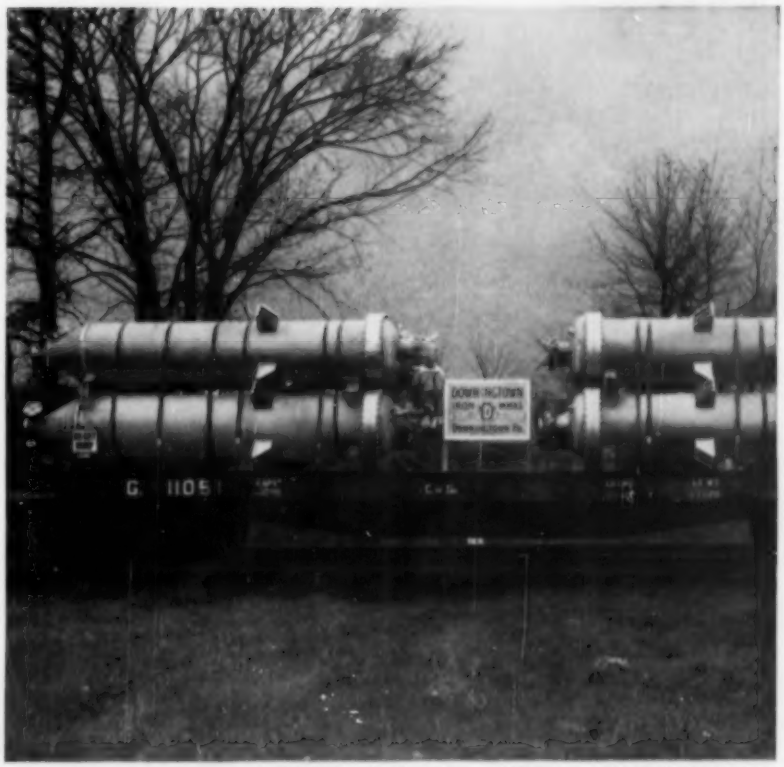
Main advantages of the process: Higher efficiencies, utilization of waste heat. □

Co-operative venture that will aid the process industries in the Kansas-Oklahoma area, including Kansas City, Mo., is the agreement between Brown Fintube Co., Elyria, O., and Western Supply Co., Tulsa, Okla., under which Western becomes sales representative for Brown's heat transfer line. At the same time, Western will be enabled to go more deeply into the problems of the use of finned surfaces in shell-and-tube applications. □

Two new plants for the production of Styrofoam, Dow's plastic foam, will be built by Dow at Ironton, O., and Riverside, Mo. □

A research contract for research on synthetic rubber manufacturing processes has been awarded by Shell Chemical Corp. to the Government laboratories at the Univ. of Akron. Work is expected to be completed by June 1956. □

A two-year option has been taken on a new monozite (an ore of thorium and the rare earths) deposit by Lindsay Chemical Co., West Chicago, Ill. The deposit, located in northwestern Saskatchewan, holds the potential of being an important source of thorium. □



Another carload shipment of 8 process tanks, each 52" O.D. by 13'0" long, fabricated at Downingtown of stainless steel, type 304.

REPEAT ORDERS PROVE

Downingtown built means quality

These eight stainless steel process tanks form just one of many carload shipments ordered by one customer during the past several years.

Complete satisfaction with workmanship, price and delivery—that's why so many leading chemical, refinery and other process plants turn to Downingtown again and again with repeat orders for their complex plate fabrication work.

They know they can call on our experienced staff of engineers to help work out complex design and construction details. They know they can rely on Downingtown skill and experience for quality workmanship. They know Downingtown is thoroughly experienced in working and welding many alloys and clad materials, as well as the carbon steels and stainless steels.

Put your plate fabrication problems into experienced hands—at Downingtown Iron Works. Code work a specialty, and authorized insurance company inspection regularly available.

For further information, send for bulletin PF.

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Downingtown, Pennsylvania
New York Office: 52 Vanderbilt Avenue, New York 17, N. Y.

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Are you using wire cloth or wire cloth parts which must be corrosion resistant? Are the service conditions in your plant really tough? If you have a problem selecting the proper anti-corrosive alloy, Newark Wire Cloth may have the answer.

Available in all corrosion resistant metals, Newark Wire Cloth is accurately woven in a wide range of meshes, ranging from very coarse to extremely fine.

If you have a wire cloth problem involving corrosion, please tell us about it . . . we may have the answer.

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A complete line of woven wire cloth and wire cloth parts in all malleable metals.

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Newark Wire Cloth COMPANY

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SILICONE EXPANSION BOOMS PRODUCTION

Final unit in Dow Corning's expanded silicone facilities is now completed, marked by immediate price drop.

Completion of the final unit in a $16 million plant expansion program that will more than double its capacity of methyl siloxane, has caused Dow Corning to announce an immediate 7½% price cut for its dimethyl silicone fluids and emulsions.

Since their development during World War II, silicones have been among the fastest-growing specialties in the chemical industry. Dow Corning, world's first and largest producer of silicones, has

Complexity of silicone materials is partially seen by the complex maze of pipes and tanks needed to produce them at Dow Corning's new plant.

Some of the most "hair-splitting" production line separations in the chemical industry are done in these fractionating towers at the Dow Corning plant, where silicone intermediates with boiling points only 3° C. apart are separated.

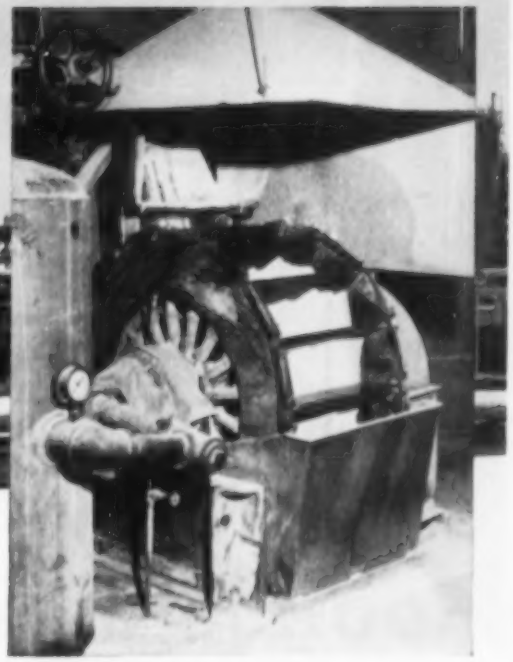
seen its sales rise from $2 million to almost $22 million in the last ten years —a phenomenal growth of nearly 40%/yr.

The Key—Versatility

Key to the great success of silicones lies in their versatility. First used in

(*Continued on page* 84)

PROCESSING FOR PROFIT



. . . with CB&I equipment

The chemical industry literally *"processes for profit."* And it's CB&I structures such as the stripper and absorber towers, accumulator tank and Conkey dewaterer shown above that help to make the profit.

Chicago Bridge & Iron Company has the experience, ability and facilities to design, fabricate and erect equipment to the exacting requirements that will enable you to *process at a profit*. When planning steel plate structures write our nearest office. Let CB&I provide you with the best when your requirements are the greatest.

Left Above: One 6½-ft. diam. by 73-ft. stripper tower, a 5½-ft. diam. by 88½-ft. absorber tower and a 6½-ft. diam. by 20-ft. accumulator tank fabricated and erected by CB&I at the National Petro Chemical Company, Tuscola, Ill. for the Lummus Company.

Above: Excess water is removed from washed aluminum oxide abrasive by Conkey Rotary Hopper Vacuum Dewaterer.

CBI

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SERVICE REPORTS ON THIS PACKING EVEN SURPRISED US!

Typical Service Reports on Lattice Braid Asbestos Packing with Teflon:

- Outlasted another Garlock Style 10 to 1 against blending waxes and steam for cleaning.
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- Outlasted other packings 3 to 1 against cold water.

Don't take our word for the greater strength, longer life of LATTICE BRAID with Teflon—try an initial order of 10 or more feet today. The Teflon core and impregnation resist everything except molten alkali metals and some freons.

And, remember, LATTICE BRAID with Teflon is only one of the Garlock 2,000 . . . two thousand different styles of packings, gaskets, and seals to meet every conceivable need. It's the *only* complete line available. It's one reason why you can expect unbiased recommendations from your Garlock representative. Call him, or write for booklet 131.

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Packings, Gaskets, Oil Seals, Mechanical Seals, Rubber Expansion Joints

INDUSTRIAL NEWS

SILICONE EXPANSION

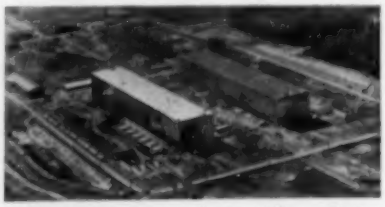
(*Continued from page 82*)

the rubber industry as release agents for truck and passenger tires, they soon branched out into a myriad other uses. A major use was found in the development by Dow Corning of silicones as polishing agent in car and furniture polishes. Some other uses are: damping media, liquid springs, anti-floating agents in paints, liquid dielectrics, special lubricants for rubber and plastic bushings and gears. Most recently they have come into use in artificial lungs and cosmetics.

With the new production, and the resultant price cuts, even more markets are expected to be opened. The new price schedules bring the prices of both dimethyl fluids and emulsions down to less than half their original level.

A plant to produce 225 tons of sulphur per day from natural gas will be built 50 miles southwest of Lethbridge, Alberta, by Canadian Gulf Oil Company, a subsidiary of Gulf Oil. □

To realize a more extensive diversification into the rapidly growing field of automation, Walworth Co., New York, a leading producer of industrial valves and fittings, will acquire the Conoflow Corp., Philadelphia, a producer of final control elements, including automatic control valves, pneumatic power operators, etc. Conoflow will operate as an independent subsidiary. □



Construction is proceeding rapidly on Electro Metallurgical Co.'s new titanium sponge plant at Ashtabula, O. The first plant in the U. S. that will use the sodium reduction process for producing titanium (reducing titanium tetrachloride with sodium), it will produce 7,500 tons of titanium sponge per year, marks the entry of the Union Carbide division into titanium sponge production.

A Nuclear Engineering and Development Center will be built at Windsor, Conn., by Combustion Engineering, Inc. The Center will have complete facilities for the design and development of nuclear power reactors, for the construction of reactor cores, and for the manufacture of related atomic fuel elements. Stone & Webster have been engaged as architects and engineers on the $5 million project which will begin operation late in 1956. □

THIS VALVE GOES TO SCHOOL!

In spite of our belief that the Cooper Alloy stainless steel valve offers the best in design and operating features, we take it to school regularly. This "school" consists of continual study by field engineers observing the valve in service, by design engineers alert for new materials and construction methods, and by industry itself subjecting it to intensive examination and reporting their findings at organized Valve Clinics.

Cooper Alloy Area Valve Clinics have been held in most major industrial centers, and our in-plant clinics have been held on the spot in dozens of leading plants, including Dow, DuPont, Mathieson, Celanese, Pfizer and many others. At these meetings our staff presents its findings, listens to the findings of users, specifiers and buyers, and attempts to work out specific problems.

Arrangements for such a clinic in your own plant may be made through our Public Relations Division.

"75 Questions". . . a selection of those questions asked most often at our clinics, is available on request.

Valve & Fitting Division

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CORPORATION • HILLSIDE, N.J.

35% NICKEL

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15% CHROMIUM

Furnace Castings

Here are two good examples of our work in high-nickel castings!

These are in the Duraloy HT group calling for Ni 33.37 percent. We've gone as high as 68% nickel on some castings where extremely high temperatures and very severe corrosive conditions had to be resisted. The important factor concerning castings for exceptionally high temperatures is that they must retain their structural form under load.

Knowing just how much nickel to put in and how much chromium and other alloying elements depends to a large extent on experience . . . and it is experience that we can offer you for the castings you need. We've been producing static castings since 1922 and centrifugal castings since 1933, being among the pioneer founders in each class.

If you would care to have our metallurgist study your casting problem, we shall be glad to have you call upon us for the service.

Our New General Catalog is yours for the asking.

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DETROIT OFFICE 23408 Woodward Avenue, Pleasant Ridge, Mich.

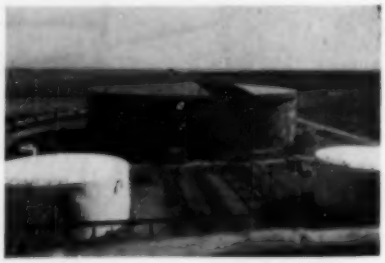
CHICAGO OFFICE 332 South Michigan Avenue

INDUSTRIAL NEWS

In one hundred pages the engineer can now find the accumulated experimental data of 100 years' work on the thermodynamic properties of pure gases and liquids. Working with 82 compounds of wide range in composition, the Engineering Experiment Station at the Univ. of Wisconsin has come up with the 100-page report. Condensation of so much data has been made possible by extending the theory of corresponding states to include a third variable, the critical compressibility factor. □

By acquiring the assets of the Saturnium Corp., Michigan Chemical Corp. has entered the rare earths field. □

The Seventh National Plastics Exposition, to be held June 11-15 in New York, will have the chemical industry as a major supporter. Some 50 leading chemical companies have already contracted for space at the Exposition, will display all the many products they supply to the plastics industry.



Construction nears completion on one of the largest steel tanks in the world, the 323,000-barrel aqua ammonia storage tank at Phillips Chemical's Cactus plant near Etter, Tex. The huge tank covers nearly an acre of ground, measures 220 ft. across, 48 ft. high.

One of our outstanding chemical reference libraries, in the Chemists' Club in New York, has recently undergone extensive renovation, is now embarked on its annual fund drive.

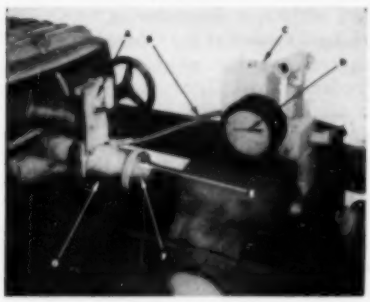
The library, located at 52 East 41st Street, is used by members of the club, but is also open to the general public every day during business hours to give service to the whole chemical industry. Not confined to use by chemists or chemical engineers, the library is available to executives in the field, to market researchers, sales engineers and executives, and anyone who has need to handle chemical literature, including the students. □

"Recruiting The Engineer" will be the subject of the Tenth Industry-Faculty Conference at the Engineering Experiment Station of Louisiana State University to be held at LSU March 1-2. □

HYDRO-LOCK

THE NEW HYDRAULIC FILTER PRESS CLOSER

Converts any manually operated filter press to hydraulic operation *in less than one hour;* enables repeated closing to a uniform pressure; no opening space in the press is sacrificed to accomodate the Hydro-Lock.



A-MOUNTING BRACKET
B-CONNECTING HOSE
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E-LOCK RING
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G-HYDRAULIC CYLINDER

Designed for long wear and safe "one-man" operation, the Hydro-Lock modernizes out-moded manually operated presses.

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asphalt
solvents
greases
inks
latex
oils

With the new portable Brookfield *eight-speed* viscometer you can, *at the flick of a switch,* easily measure the viscosity of any fluid . . . readings down to 1/5 of 1 per cent with materials having viscosity of from 1 to 32 million centipoises.

If speed, accuracy, and versatility count with you, demand the new Brookfield eight-speed viscometer. A complete line of accessories makes the Brookfield adaptable to any viscosity measurement problem. Your prompt inquiry will bring complete information. Technical assistance available without obligation.

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Many commercial filtration processes are troubled with slurry that contains slimy fines, gelatinous or minute particles. In a large number of such cases the use of E & D filter paper as a "cover" over the filter medium will provide finer filtration while protecting the medium. The cost of the paper is sufficiently low to warrant peeling it off and discarding after use leaving the medium underneath relatively clean. Savings in production time can be substantial.

Write for our FILTRATION ANALYSIS REPORT. We will recommend the proper grade for your use and send free samples for testing.

E&D FILTER PAPER

THE EATON-DIKEMAN CO.

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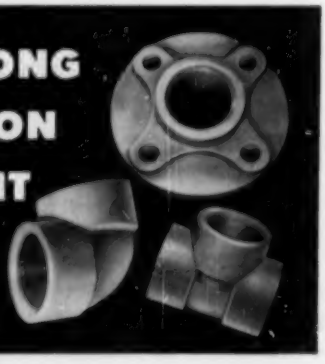
The only company in America exclusively devoted to the manufacture of filter paper for science and industry.

FOR STRONG CORROSION RESISTANT PIPING



Specify these injection-molded PVC fittings and flanges

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TUBE TURNS PLASTICS, INC.

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Call your TUBE TURNS PLASTICS' *Distributor*

INDUSTRIAL NEWS

The nation's largest vacuum melting furnace is now in operation at Vacuum Metals Corporation's Syracuse, N. Y., plant. Remotely operated by the melter, the 2,200-pound furnace has its melting unit enclosed in a ¾-inch thick airtight and liquid-cooled stainless steel chamber. The design makes it possibe to charge, melt, pour and remove ingots without affecting the vacuum in the melting chamber.

Between ten and fifteen nuclear reactors will go into operation in Canada within ten years. Included in this estimate are the first large low cost power station and some portable units for use in helping to develop the Northwest wilderness of Canada. □

Ten chemical engineering positions are now vacant at the Chemical Corps research center at Camp Detrick, Frederick, Md. These are Civil Service appointments, carry all Civil Service benefits, pay from $4345 to $8990 depending on the grade of the position. □

Synthetic latex plant, costing in excess of $1 million will be built at Pittsburg, Cal., by Dow Chemical. It will produce a broad range of styrene-butadiene latexes. □

A model of a high-pressure vessel closure, designed for use in measuring stresses in the bolts when pressures up to 16,000 lb./sq.in. are applied, guides the design of closures for C. F. Braun & Co. in its Alhambra, Cal., laboratory.

Stress measurements are made with SR-4 resistance wire strain gages bonded on four bolts spaced 90° apart. The gages are connected into a Baldwin-Lima-Hamilton SR-4 strain indicator which will measure bolt stresses when the top of the closure (left) is properly seated on the sealing gasket and either gas or liquid pressure is applied to simulate process conditions. The method gives greater accuracy in much less time than any other method of measurement, according to Braun engineers.

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makes simple work of Filtering, Mixing, Storing

Regardless of the size or type of your installation, whatever your process may be, there's an Alsop Filter, Mixer, and Storage and Mixing Tank to "fit your job," you can be sure of getting from Alsop the right unit properly applied—you can depend on Alsop proved performance features. Alsop Filters, Mixers, and Tanks are available in a complete range of sizes and capacities, and Alsop Equipment is custom fitted to your application by engineers who have thorough experience in Filtration and Agitation. For full information, recommendations, and quotations write Alsop Engineering Corporation, 1010 Gold Street, Milldale, Connecticut.

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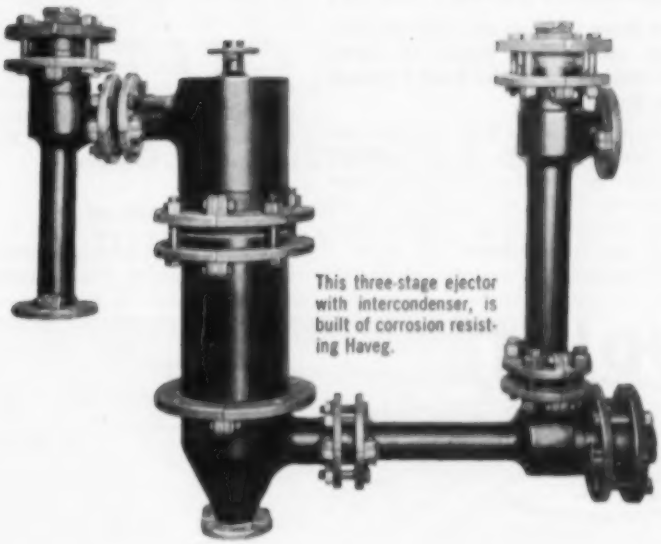
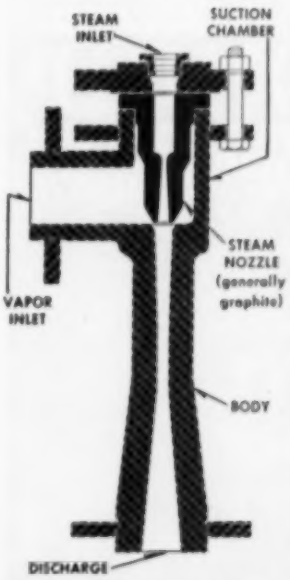
Designed to handle corrosive vapors



This three-stage ejector with intercondenser, is built of corrosion resisting Haveg.

ELLIOTT *Steam Jet* EJECTORS

TYPE H



Cross-section, showing construction details of Type H ejector. Conventional split flanges are used. Nozzle is easily replaceable.

When it comes to maintaining vacuum, while handling highly corrosive vapors, you can't beat these durable Elliott Type H ejectors. Made of Haveg, Permanite or similar corrosion-resistant synthetic resin material, they'll stand up to hydrochloric and sulphuric acids, wet chlorine, caustic, benzene and many other corrosive vapors, including some of the chlorinated aromatic compounds.

Whatever your vacuum requirements, take advantage of the experience and know-how of an Elliott ejector specialist. There's no obligation on your part. Contact your Elliott representative or write Elliott Company, Jeannette, Pa. for descriptive bulletins.

ELLIOTT Company

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ROCKY MOUNTAIN ENGINEERS MAKE SALARY SURVEY

How does your area, your salary, stack up against those of chemical engineers in the Rocky Mountain Region?

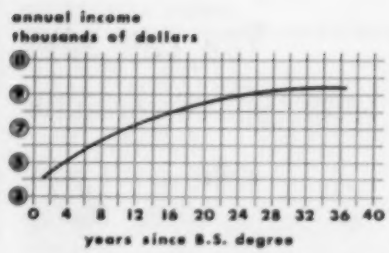
When a national or large-regional salary survey is made it is, naturally, weighted by the areas of heavy industrialization. What of the areas, like the Rocky Mountain Area, where industrialization is less intense?

To answer the question of exactly how engineers' salaries in the Rocky Mountain region do stack-up against those of more heavily industrial areas, A.I.Ch.E.'s Rocky Mountain Section initiated a salary survey, under the direction of G. C. Lammers.

The survey attempted to obtain a cross section of chemical engineers in the area without regard to society membership, showed a 60% return on questionnaires of which some 30% were non-A.I.Ch.E. members.

Results—Lower Salaries

A glance at the salary curve, the result of smoothing yearly averages and



valid within $200-300 per year, shows the main result of the survey: Colorado chemical engineers receive less income than those located elsewhere.

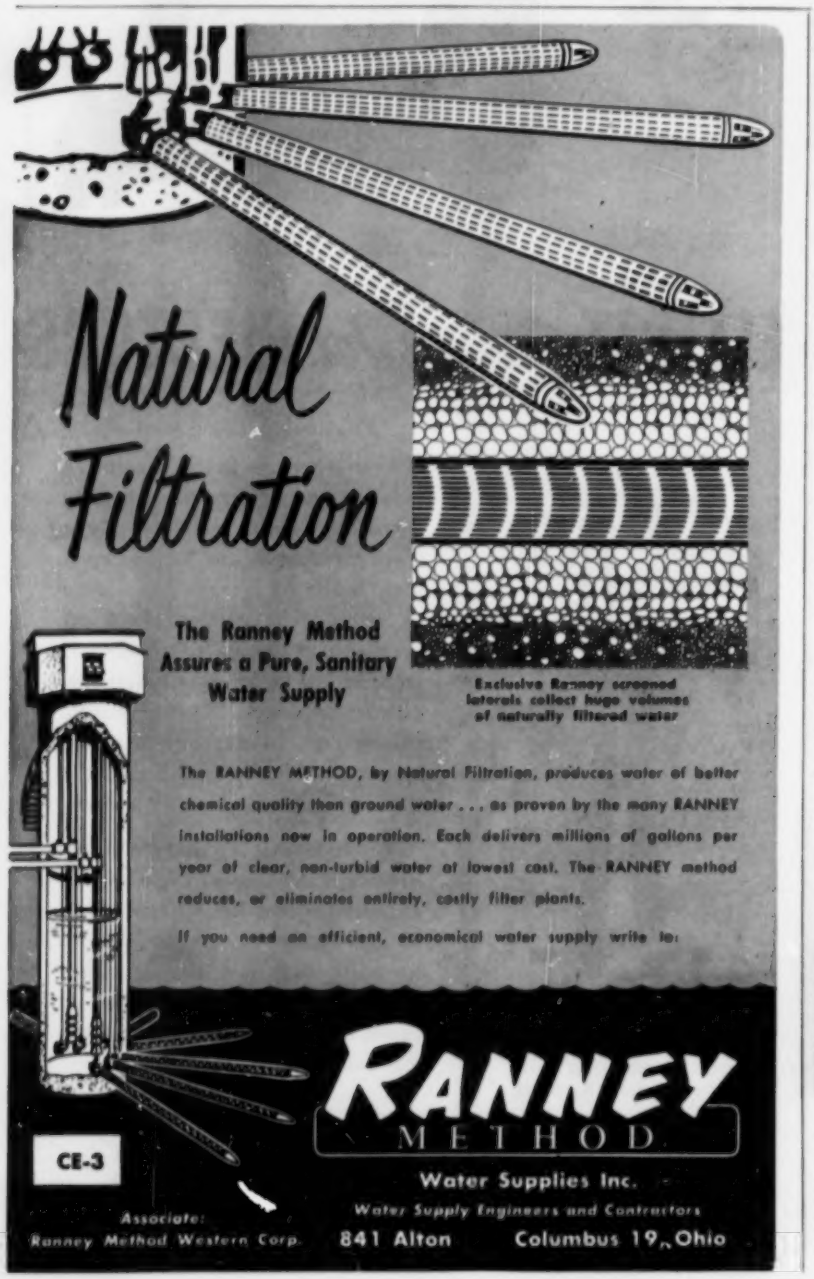
Comparisons of this curve with the December 1952, A.I.Ch.E. national survey, and a recent New York survey, show Colorado salaries paid to those with 2-6 years experience run some $200-500 a year behind New York and the nation as a whole. After 6 years experience the gap widens rapidly to a Colorado lag of from $4,000-6,500 a year in the upper experience ranges.

Sidelights

One of the most interesting indications in the survey was the lack of correlation between the advanced degree and remuneration. Because this was found to be true in the Colorado area, the curve is a single line on the coordinates of salary and experience. Difference in academic degree seems to make little difference in salary levels.

Engineers in production showed a consistently greater income, by about a $1,000 per year on the average. This is probably due to the fact that much Colorado industry is new, and new industry generally tends to employ more top men in production.

The survey also tended to show that A.I.Ch.E. membership increased financial rewards by some $900 a year during the middle part of the chemical engineer's career. In early and late stages it seemed to make little difference.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Iraq's first complete oil refinery, designed, engineered and built by The M. W. Kellogg Co. and its subsidiary, Kellogg International Corp., for the Iraqi government, is now on stream near Baghdad. A 24,000 bbl./day thermal refinery, the installation has two unique features—a sulfuric acid plant and a can manufacturing plant which will produce and fill 15,000 five-gallon cans per day.

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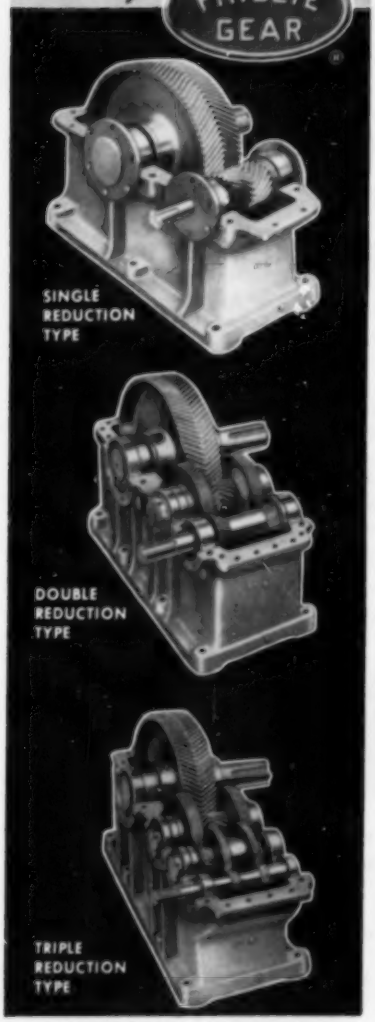
...by PHILLIE GEAR



For high horsepower reduction with heavy shock loads, Philadelphia Herringbones are the answer. These quality units are available in Single, Double and Triple Reductions offering wide selection of capacities and ratios. Continuous tooth type herringbone gears assure evenly distributed pressure over each tooth from top to working depth line — which means long life, minimum vibration, quiet operation and maximum transmission . . . Be convinced, send for Catalog H-55.

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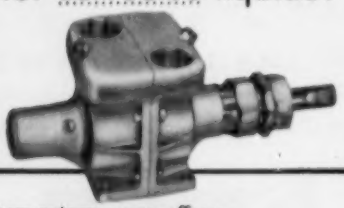

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Available from stock, suitable for direct motor, V-belt or vari-speed pulley drive, the Eco All-Chem handles organic, inorganic, hazardous and radioactive fluids with complete dependability.

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CANDIDATES FOR MEMBERSHIP IN A. I. Ch. E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III, Section 8, of the Constitution of A.I.Ch.E.

Objections to the election of any of these candidates from Members and Associate Members will receive careful consideration if received before March 15, 1956, at the office of the Secretary, A.I.Ch.E., 25 West 45th Street, New York 36, N. Y.

Member

Enslen, Gerald E., *Wilmington, Del.*
Fair, James R., Jr., *Emeryville, Calif.*
Gloskey, Carl R., *Avenel, N. J.*
Goodwin, Donald R., *Pittsburgh, Pa.*
Gossett, F. M., *Charleston, W. Va.*
Hein, Lawrence, *New Haven, Conn.*
Hill, Preston L., *Dayton, Ohio*
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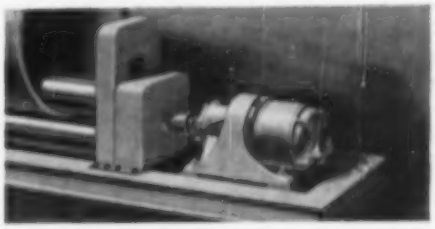

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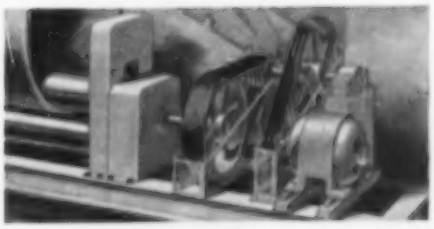

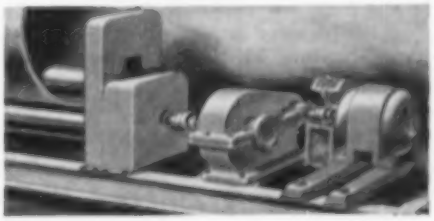

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CHEMICAL ENGINEERING IN PULP AND PAPER INDUSTRY

It is time the "art" of papermaking gave way to the science of the chemical engineer. This was the crux of a recent symposium held by Washington-Oregon Section.

"Fundamentally, the paper machine is a combination of unit operations involving fluid flow, filtration, and heat transfer. However, papermaking is still considered to be an art, depending to a great extent on the human element for maximum quality production. There is need for a chemical engineering approach to the problems of papermaking instead of the present trial and error method being so widely used."

Here, in the talk by F. R. Hamilton, general superintendent of Simpson Paper Co., Everett, Wash., on "Paper Making as a Combination of Unit Operations," is the heart of the Pulp and Paper Symposium sponsored by the **Washington-Oregon Section** at Everett. Seventy-five engineers attended, heard Hamilton go on to discuss in detail the many unsolved problems under each of the basic operations, problems the chemical engineer can and must solve if papermaking is to become a true science rather than a "seat-of-the-pants" art.

Conventionally, bleach liquor is made in a batch process, on the standard hit and miss method involving little true chemical engineering. Not only is this hard to control properly, pointed out J. H. Hull, chief process engineer, Central Engineering Office, Crown Zellerbach, Seattle, but it is less economic than the continuous bleach liquor manufacture method he presented to the symposium in his paper. Hull showed the flowsheet for the process, indicated that not only is it more susceptible to an engineering approach, with its process equipment, instrumentation, and control potential, but is also more economic.

Engineering Value Demonstrated

The results that can be achieved by applying chemical engineering to the paper and pulp industry were typified in the talk of G. D. Huston, chemical engineer, Puget Sound Pulp and Timber Co., by following the growth of the acid plant at the company's main installation. Originally, the calcium-base acid was made by the cold acid system. Control difficulties, acid strength limitations, and the absence of heat and sulfur recovery, were strong defects. The gradual evolution of the acid plant to the hot acid (chemi-pulp) system was accomplished through the addition of an SO_2 absorption column and low and high pressure acid accumulators. Now a return to the original system of acid making would require some 25% more sulfur and 90% more steam to produce pulp at half the present rate!

Entry of chemical engineering into pulp making at Puget Sound's acid plant was characterized in part by the introduction of an SO_2 absorption column. This whole matter of the ammonia-based sulphite pulping process is of considerable engineering interest today, was analyzed in detail by L. J. Gordon, Scott Paper. Plant conversion from calcium to ammonia-base does not usually require extensive equipment alteration, although raw acid preparation, largely an absorption operation, does warrant consideration. In the design of an absorption system, the major variables include: stoichiometry of the system, thermal effects, equilibrium solubility, cross-sectional area of the tower, gas and liquor rates, type of tower, and tower height.

The symposium was brought to a solid conclusion at the evening dinner meeting, where R. E. Baker, Pulp Division, Weyerhaeuser Timber, went into the "Responsibilities of Chemical Engineers in the Pulp and Paper Industry."

NUCLEAR, SALES ENGINEERING TOPICS LEAD LOCAL SECTIONS

Glass, economic matters, official regulations and automation, are among other subjects presented at local section meetings.

Deep and fundamental interest of chemical engineers in nuclear engineering is demonstrated this month by meetings of three local sections. The design, construction and operation of the first homogeneous power reactor at Oak Ridge, and the construction and operation of the borax reactor that supplied power to Arco, Idaho, in the first commercial use of atomic power, were presented in two films shown at the December meeting of the **Savannah River Section** (*C. L. Howard*).

Radio-isotopes are currently the principal peacetime product of the atomic energy program. Applications in this field of particular interest to chemical engineers were discussed by C. E. Crompton, Isotopes Division, AEC, and the members of the **Knoxville-Oak Ridge Section** (*R. J. McNamee*) at the Section's November meeting. Already the isotopes are proving industrially important for the analysis of alloys, thickness control, analysis of hydrogen-carbon ratio in operations of the petroleum industry, control of catalyst flow, and flow rate measurement by means of an injected radio-isotope and an integrating counting technique. The potential for radio-isotopes in industry is great, it remains for the engineer to realize it.

In a more general vein, R. Kobelman, technical director of atomic energy for Sylvania, discussed the entire field of atomic energy and industry, drawing on his company's wide and growing experience in the field, at the first meeting of the new **Central Pennsylvania Section** (*W. E. Keppler*) held in November at Muncy, Pa. The section is off to a good start.

Sales Engineering

From atomic energy to sales may seem a big jump, but it is all in a day's work to the chemical engineer.

Unlike the general consumer selling operation, industrial sales is very much a two-way road. This sales-purchasing relationship was examined by J. Minevitch, engineering consultant, and Mack Jones, a purchasing agent for DuPont, at the December meeting of the **Western Massachusetts Section** (*R. T. Bogan*). Primary fact is: The purchasing agent considers the salesman as an important part of his purchasing team. The purchasing agent must depend a great deal on the salesmen he meets for the success of his purchasing, and will utilize the company whose salesmen are the most reliable, most helpful, and who use the "five knows" that distinguish the top salesman from the average one: Knows his customer's business opportunities; knows his own company; knows his products; knows his customer; knows himself. In essence, this boils down to the simple fact that the sales engineer is there to "help" the purchasing agent to buy, not to "sell" him in the conventional sense of the term.

Following the same essential theme,

J. K. Marshall, Carbide and Carbon, pointed out to the November meeting of the **Charleston (W. Va.) Section** (*G. A. Trigaux*), that the technical representative is no longer the peddler of yesterday, and how he evolved from that peddler. And, shifting the base a little from the salesman to advertising, P. B. Slawter, Jr., of G. M. Basford, emphasized to the December meeting of the **New York Section** that the industrial buyer cannot be "taken-in" by the kind of advertising common in the general consumer press. The engineer who buys is the "best informed buyer in the world," and the engineer who sells must be equally well-informed, both as to his product and his methods of advertising that product.

Glass—And Government Control

Glass in industry held the floor at the December meetings of the **Rhode Island Section** (*A. R. Thompson*) and the **East Tennessee Section** (*P. C. Underwood*). At the former, A. Marzocchi showed the great versatility of the glass fiber industry in its application to industry (re-inforced plastic tanks, insulation, etc.) and to consumer goods (curtains, rope hawsers, etc.). For East Tennessee it was a remarkable film, "Glass and You" put out by Corning Glass, which ran the gamut of consumer and industrial uses for glass, including the industrial glass tough enough to drive a spike, borosilicate glass used for industrial research and manufacturing, glass for architecture, glass tubing for industry machine-drawn at a rate of 20 miles/hour or more, glass-lined equipment, and much more.

Two instances of government regulation involving industry came under the scrutiny of local sections—one drawing applause, the other, nays.

The vote of confidence occurred at the **Maryland Section's** (*G. C. Schmitz*) December Meeting, where H. Silverman, State Water Pollution Control Commission of Maryland, emphasized the "voluntary" nature of the state's work with industry to control water pollution. Legal compulsion is rarely resorted to in Maryland, voluntary cooperation being considered far better, and the state has done an excellent job in the knotty problem of exactly defining and delineating the properties of permissible effluent. Careful study has already resulted in a wider latitude of effluent properties than heretofore thought possible.

The nay came at the December meeting of the **Chicago Section** (*S. G. Sourelis*), where J. M. Patterson, Standard Oil, analyzed the results of court imposed Federal control of natural gas production. Main result, according to Patterson: Sharp decrease in new supplies which will mean higher prices.

Loss of incentive is already apparent, Patterson said, competition is stifled. Prescription: The Senate should pass the already-House-passed Harris Bill, which removes direct controls from producers, but guarantees to consumers the protection of reasonable field prices.

Economics—And Corrosion

Suppose you want to determine the most profitable product mix, given such factors as purchase and selling price and manufacturing capacities? Mathematical set-up is easy, but finding the maximum or optimum for your system turns out to be far from obvious. The January meeting of the Philadelphia part of the **Philadelphia-Wilmington Section**, went a long way toward solving this dilemma by hearing of a new mathematical technique called "linear programming," from G. H. Symonds, Esso Standard. Linear programming allows the complex problem to be handled with simple arithmetic. In a more general discussion of engineering

(*Continued on page 96*)

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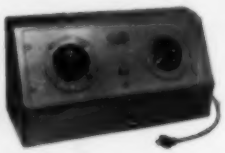

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News of the Field

FROM LOCAL SECTIONS

(*Continued from page 95*)

economics, by R. D. Williams and R. J. McNally, American Smelting and Refining, a hypothetical sulfuric acid plant installation, with prepared cost analysis and break even charts, was used to demonstrate general principles to the **Intermountain Chemical Engineers' Club.**

The basic studies of stress-corrosion are still far from complete, D. K. Priest, Pfaudler's research laboratory, told the November meeting of the **Twin Cities Section** (*P. E. Thorson*), but the two main theories as to cause are electrochemical, from formation of local anodes, or mechanical plus electrochemical, from disruption of a protective film. It can be counteracted by using stress-relieved metals as well as those having a very low level of impurities, or with proper cathodic protection.

Automation

In a lively panel discussion at the November meeting of the **Cleveland Section** (*J. L. Miller*), held in conjunction with the Cleveland Engineering Society, automation and process control came in for a thorough discussion from three different angles. Stan Arthurs, Standard Oil of Ohio, used a detailed chart to show how the oil industry, manufacturing a liquid, is particularly adapted to automation, how it has been using automation since long before the word itself was coined, and how the trend towards automation is as much due to improvements in product control as to the need for reducing labor costs.

From the strict chemical angle, R. C. Rahn, Diamond Alkali, described a case in his own company where automation is not just a word but an absolute necessity. At Diamond's anhydrous hydrochloric acid plant the entire output is pumped directly to Naugatuck's nearby plant *with no storage facilities in either plant.* Obviously the Diamond plant must be rigidly controlled to adapt to any change in Naugatuck's needs.

A major headache in the whole field of automation is the insistence of labor and other interested parties that it will mean mass unemployment at worst, extreme work-force dislocation at best. To this T. J. Walsh, chemical engineering professor at Case Institute, disclosed the statistics he had presented to the Congressional Committee investigating the subject. From 1949 to 1950, in spite of increasing automation, there was an increase of 5% in total employment in the chemical and petroleum industries.

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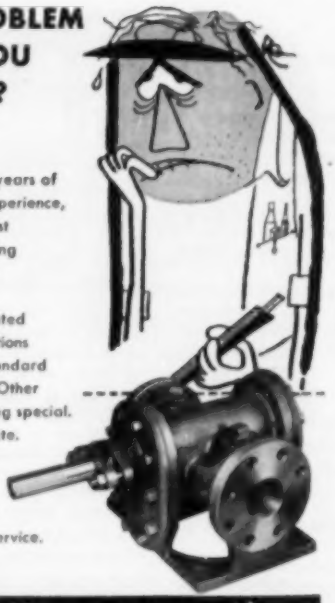

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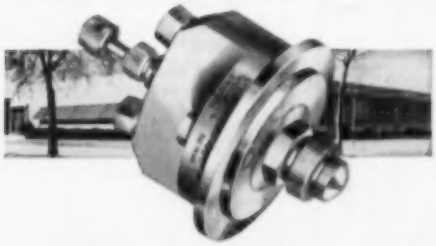

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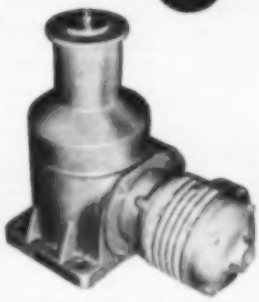

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FUTURE MEETINGS and Symposia of the Institute

See page 55 for a preview of New Orleans attractions.

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General Papers

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Nuclear Engineering Division Congress and Atomic Exposition, Philadelphia. "The Fuel Cycle."

■ ANNUAL—BOSTON, MASS.

Dec. 9-12, 1956. Hotel Statler.

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CHAIRMAN: F. M. Tiller, U. of Houston, Cullen Boulevard, Houston 4, Tex.

The flow of liquids through compressible media, with experimental and theoretical papers.

Low Temperature Techniques

CHAIRMAN: Dr. Clyde McKinley, Air Products, Inc., Allentown, Pa.

The Sales Engineer in Chemical Engineering

Afternoon at the Ichthyologists

General Session: "Obsolescence" of Chemical Engineers. Sunday P.M.: Round table discussion.

Deadline—August 9, 1956

■ BEAUMONT, TEXAS

March 9, Lamar Tech.

Third Annual Joint Technical Meeting of Sabine Area Section, A.I.Ch.E. and Texas-Louisiana Gulf Section, A.C.S.

All-day session on: gas chromatography, fluid catalyst attrition, operations research, creative thinking, anhydrous caustic corrosion, failure of process equipment, & gas turbine applications.

■ TERRE HAUTE, IND.

April 21, 1956. Rose Polytechnic Institute.

1-day meeting on Bio-Engineering sponsored by the Terre Haute Section, A.I.Ch.E.

CHAIRMEN: C. W. Smith and R. A. Shurter. Contact Mr. Shurter at Commercial Solvents Corp., Terre Haute, Ind.

UNSCHEDULED SYMPOSIA

Laboratory and Pilot Plant Techniques

CHAIRMAN: Thomas S. Leary, Calco Chemical Div., American Cyanamid Co., Bound Brook, N. J.

Centrifugation

CHAIRMAN: James O. Maloney, Dept. of Chem. Eng., U. of Kansas, Lawrence, Kan.

Fluidization of Solids

CHAIRMAN: E. R. Gilliland, Chem. Eng. Dept., M.I.T., 77 Massachusetts Ave., Cambridge 39, Mass.

Drying

CHAIRMAN: Ralph E. Peck, Chem. Eng. Dept., Illinois Institute, 33rd Federal, Chicago 16, Ill.

Cost of Unit Operations

CHAIRMAN: John Happel, Chem. Eng. Dept., New York U., University Heights 53, N. Y.

Size Reduction

CHAIRMAN: Edgar L. Piret, Chem. Eng. Dept., U. of Minnesota, Minneapolis 14, Minn.

(Continued on page 100)

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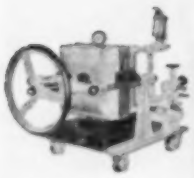

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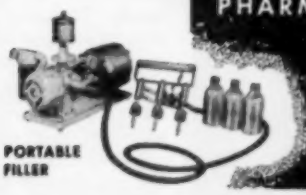

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Jet Apparatus Ask for Commercial Bulletin J-1 | Nolometers & Flow Indicators Ask for Condensed Bulletin 10 NA | Valves Ask for Condensed Bulletin V-1 | Heat Transfer Apparatus Ask for Condensed Bulletin HT-1 | Vane Pumps Ask for Bulletin 17-A

Pumping Progress Report

FOR CHEMICAL ENGINEERS

An advertisement prepared by The Aldrich Pump Co., Member of Hydraulic Institute, U.S.A.

SPACE, in many pump installations, is a major problem. Another is the necessity for special foundations. For new installations these factors may dictate elaborate construction; for replacement or modifications of existing systems, expensive piping and equipment changes.

COMPACTNESS OF DESIGN, while often desirable, is not necessarily the answer. Simplicity of design may be a better solution.

SIMPLICITY OF DESIGN brought about the first Inverted Triplex and Quintuplex and ultimately Septuplex and Nonuplex Pumps. This Aldrich design innovation brought to users economies of space, maintenance and operation they had never known. And even more important, Multiplex pumps brought new freedom from pulsation.

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Leakproof
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for Batch or Continuous Operation
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Cake stays in place even when run is interrupted
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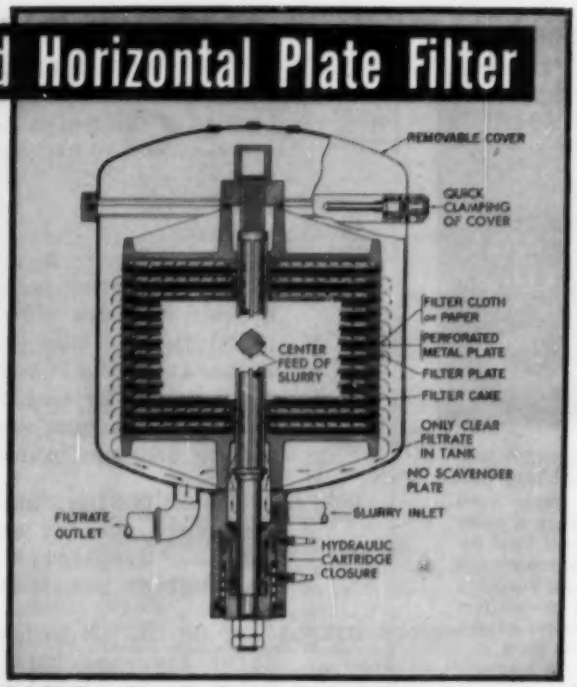

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people

Robert Lindley Murray, chairman of the Board of Directors of Hooker Electrochemical Co. has been awarded the Chemical Industry Medal for 1956 in recognition of his contributions to research, engineering, and administration in the chemical industry. He will receive the medal at the Waldorf-Astoria Hotel following a dinner in his honor on April 27, 1956. In addition to being twice a director of A.I.Ch.E., Murray is the author and co-author of many papers dealing with the chlorine and alkali industry and is a recognized authority in the field.

James Y. Oldshue becomes director of research of the Mixing Equipment Co., Inc., Rochester, N. Y. He is chairman of the Agitator Testing Procedure Committee of A.I.Ch.E. and has been engaged in fundamental and applied research in fluid mixing since joining his firm in 1950.

FUTURE MEETINGS and Symposia of the Institute

(Continued from page 98)

MEETINGS **SYMPOSIA**

Corrosion Resistant Alloy Materials of Construction

CHAIRMAN: G. Fred Our, Carbide and Carbon, Charleston, W. Va.

Dry Classification of Solids

No Chairmen Assigned.

Filtration & Centrifugation

CHAIRMAN: Horace Hinds, Jr., Corn Products Refining Co., Box 345, Argo, Ill.

LOCAL SECTION Future Meetings

■ **NEW JERSEY**

March 13, 1956.

Auditorium, American Cyanamid, Bound Brook.

Gomer H. Ward, "Textile Fibers."

AUTHOR INFORMATION

Note: The Author Information column will appear quarterly in the January, April, July and October issues.

Heat and Corrosion Equipment

Processing Equipment

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ENGINEERED FABRICATION

CORROSION RESISTING ALLOY

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Welland, Ontario

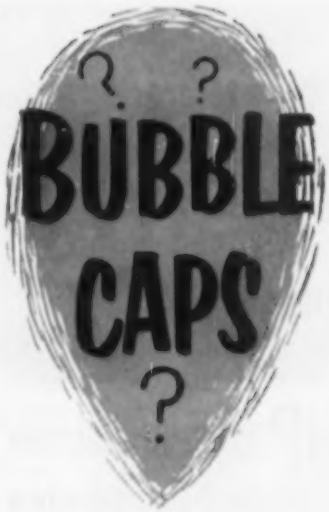
The American Oil Company announces the appointment of **John E. Kasch** (left) as manager of coordination and **Charles F. Feuchter** (below) as manager of planning in its manufacturing department. Kasch started with the company's refining affiliate at Texas City in 1942, and ten years later was transferred to New York. For the past two years he has been a technical assistant to the vice president of manufacturing. He holds a bachelor of science, master of science and doctorate, all from the Univ. of Texas. Feuchter was also with the refining affiliate at Texas City in the manufacturing department until 1942 when he moved to the manufacturing department in New York. Earning bachelor's and master's degrees from M.I.T., Feuchter served as a special assistant to the director of refining, PAD, in 1952.

George F. Kirby, with Ethyl Corp. for 15 years, elected vice-president in charge of research and engineering. He succeeds **B. Bynum Turner** recently named executive vice-president.

At the same time **F. J. Sergeys** to general manager, research and engineering operations at Baton Rouge and Houston; **P. A. McKim** replaces Sergeys as director of chemical engineering div.

Engineers Joint Council has named **Thomas H. Chilton** its president, and as such he heads an organization representing the largest group of engineers in the country, of which the Institute is a member. Chilton is in charge of engineering research and development at DuPont, and is a former president of the A.I.Ch.E.

Michigan Chemical Corp. names **Dwight Williams** director of research. Williams, to locate at research and technical labs in Michigan, has just resigned as Chief, biology and chemical branch, U. S. Army. In addition, Williams has served as professor, and researcher in industry.



Odd product? Not at all. Bubble caps are important in many process industries. To prove the point, 26 companies index this particular device in Chemical Engineering Catalog. Regardless of size or type desired ... swayed riser, pull up riser, wedge hold down, pressed or cast bubble caps ...

furnishes up-to-the-minute facts fast.

Just one product among hundreds, bubble caps are an example of CEC's great wealth and variety of data. 2000 pages of product facts furnished by over 500 companies are bound to steer you to the solution of your most difficult processing problems. For the quick answers concerning types ... capacities ... structural characteristics ... installation procedures ... maintenance, etc. of almost any kind or type of process equipment, turn first to your copy of CEC. It's bound to help you save time!

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[1] Permissible in food processing at concentrations up to 10 ppm.
[2] Permissible in food processing at concentrations up to 32 ppm.

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people

Arthur K. Doolittle is appointed senior scientist in the research department of Carbide and Carbon Chemicals Co., S. Charleston, W. Va., to direct a broad program of basic research in liquid-state physics. He joined the firm in 1932 as technical head of coatings research, and in 1944 was appointed asst. director of research. Active in Institute affairs, Doolittle, in 1955, was national vice president, and is currently working on the special Institute committee for development of professional attitudes among chemical engineers, both on the student and graduate levels.

Thorndike Saville, dean of the N.Y.U. College of Engineering, elected president of the Engineers Council for Professional Development. Saville, also president of the Engineers' Joint Council, is the first to hold both offices simultaneously.

John G. Bill elected president of Sharp & Dohme Div. of Merck & Co. Also announced was **William H. McLean** as president of the Chemical Div. of Merck. Bill comes to his head position after serving in successive other positions with the company since 1925. McLean joined Merck in 1948 as director of commercial development.

Gerhard Harold Beyer named chairman of the department of chemical engineering at the U. of Missouri. He joins the University after six years at Iowa State College. Since 1950 he has also been an associate engineer directing research at the Ames Laboratory of the Atomic Energy Commission at Ames, Iowa.

Calvin H. Corey becomes vice-president, Brooks & Perkins, Inc. With the company's entrance into field of metals and assemblies for nuclear power plants, Corey will take over responsibility for all liaison work between B & P and the atomic industry.

Martin A. Elliott, research professor at Illinois Institute of Tech. appointed director of the Institute of Gas Technology.

Ralph E. Martin announces the opening of his office in Somerville, N. J., as manufacturers' representative in chemical processing equipment in the New Jersey and Eastern Pennsylvania areas. Martin's experience constitutes 22 years in the field of spray drying and instant coffee equipment.

Graham B. Knight begins association with Joseph R. Minevitch in the practice of consulting chemical engineering in Boston, Mass. Until recently Knight has been with the Badger Mfg. Co. He has had extensive experience in process engineering and in the design and operation of refinery units and chemical plants.

How to beat your engineering-design problems

DESIGN OF PIPING SYSTEMS

By members of the engineering departments of

The M. W. KELLOGG COMPANY

The entire subject of structural design of piping systems is covered in this clear, modern, and comprehensive account. It includes the most complete and detailed treatment of the thermal expansion problem ever published and shows how this treatment is extended to calculating effects of uniform loading such as that due to weight or wind.

In addition to helping solve design problems, this volume offers excellent material for the evaluation of piping stresses: The treatment of expansion joint systems describes arrangements for large high-temperature lines in confined areas; and the discussion on pipe supports is believed to be the first organized coverage of this subject.

1956 365 pages 319 illus. $15.00

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Robert H. Cairns to director of research in Research Dept., Hercules Powder Co. Asst. director since 1945, Cairns joined Hercules in 1933 to work in successive positions with the company, taking a year's leave of absence to serve as deputy asst. secretary of defense for research and development.

Hercules appoints also **Wilbur E. Becker,** plant manager in Franklin, Va.; **Spencer H. Hellekson,** asst. director of operations in Wilmington; and **Dennis L. Molnar,** asst. plant manager at Franklin plant.

Gonzalez Chemical Industries, Inc., of San Juan, P. R., announces the appointment of **W. Standish Miller** as general manager in charge of production of its new $12 million plant now under construction in Guanica, P. R. In 1950 Mr. Miller became the operations manager of the Houston, Texas operations of the Mathieson Chemical Corp. In 1954 he was appointed director of engineering, and resigned shortly thereafter to do consulting work.

The Badger Mfg. Co., Cambridge, Mass., elects **A. J. Broggini** executive vice president and chairman of the Executive Committee. He has been a member of the Board and the Executive Committee since last year. He joined Badger Mfg. in 1952, after serving in various engineering, sales, and executive capacities with the former E. B. Badger & Sons Co.

Among recent appointments by Goodyear Tire & Rubber Co., **Albert J. Gracia** becomes manager, research and development. **D. H. Francis** succeeds Gracia as general manager, Goodyear Atomic Corp.

Also announced is **R. J. Koch** and **W. M. Saltman** to diene synthetic rubbers section, Research Div.; **J. R. Wilson** to high polymer research section; **E. M. Katt,** Bench-Scale Piloting Section.

Morton Smutz becomes head of the chemical engineering department of Iowa State College. Previously with Monsanto Chemical Co. and Bucknell U., he joined the staff of Iowa State in 1951.

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COOLERS
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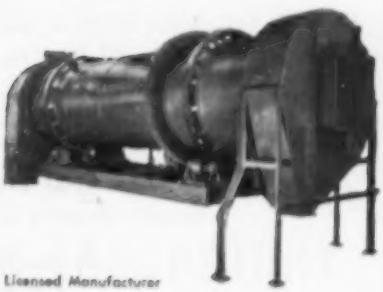
for the Chemical Industry

CONVENTIONAL DRYER
Heavy-Duty rotary unit with furnace, burner, breeching and air handling system. Used for ammoniated granular fertilizers and other chemicals. Also DehydrO-Mat Variable Inclination Dryers (Pat. pend.).



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At least eight to ten years' experience is required involving nonmetallic inorganic materials for use at high temperatures. (If directly related, time spent in obtaining an advanced degree may be considered part of this experience.) Applicant must be a graduate physical chemist, metallurgical engineer, or ceramic engineer, preferably with Ph.D. or equivalent.

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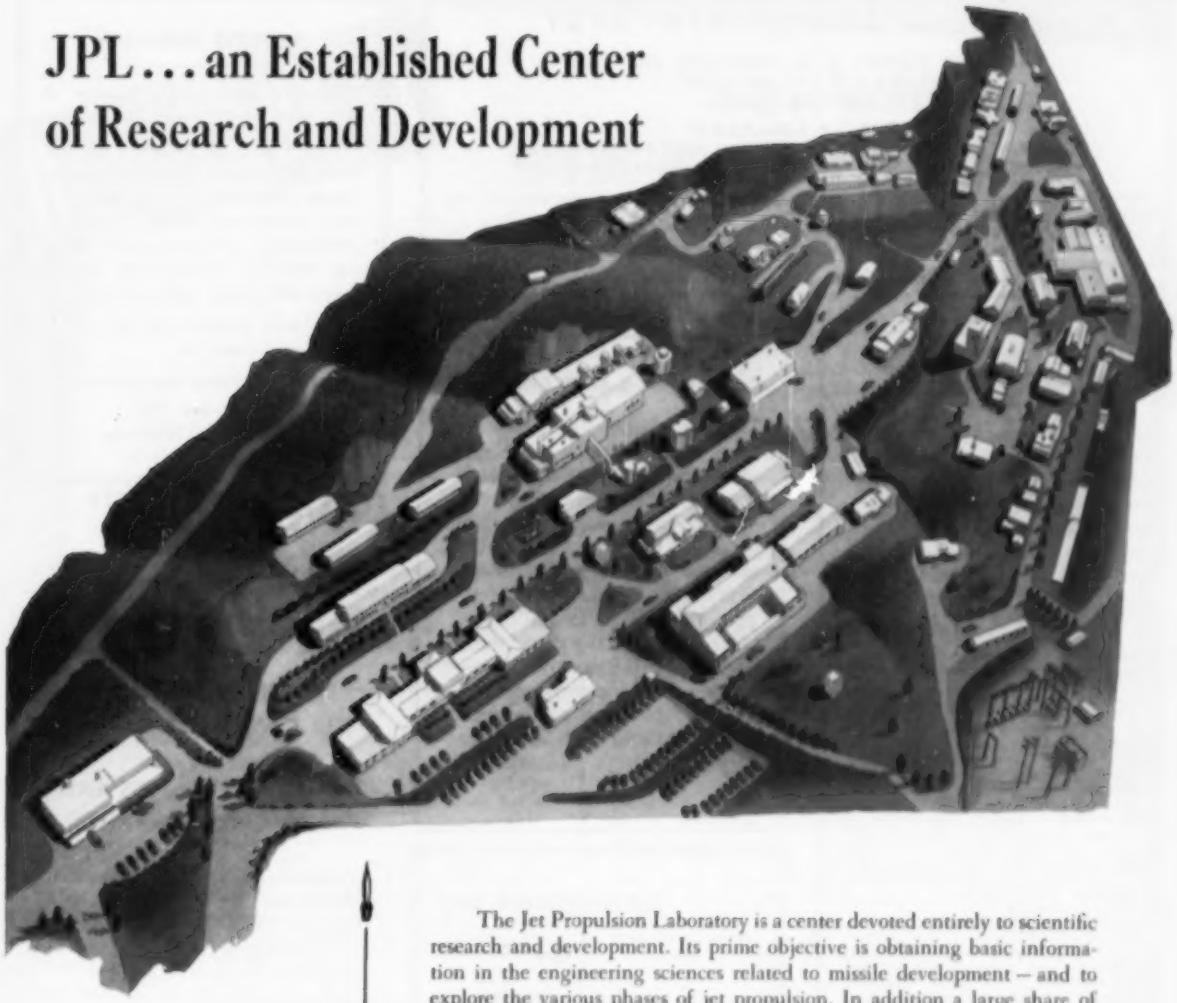

The Jet Propulsion Laboratory is a center devoted entirely to scientific research and development. Its prime objective is obtaining basic information in the engineering sciences related to missile development — and to explore the various phases of jet propulsion. In addition a large share of its program is devoted to fundamental research in practically all of the physical sciences.

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These openings are for permanent staff positions in a well-established research organization. Excellent laboratories and working conditions. Ideal location in Eastern Pennsylvania.

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Work will include process engineering closely integrated with operations of new independent refinery which includes crude distillation; catalytic cracking, reforming, polymerization; delayed coking and sulphur manufacturing.

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Successful applicant will: assist research and development groups in planning experimental work to study reactions in the development of new processes, and products; recommend types of laboratory equipment, conditions for the experiments, and data to be obtained; interpret laboratory and semi-works data; and use these data to specify size and type of plant equipment and operating conditions. Will also investigate possibilities of increasing capacities and yields through modification of existing plant equipment or operating conditions.

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Duties include: trouble-shooting on equipment, such as pipe line reactors, fluidized solids reactors, and film driers, where heat transfer is one controlling factor; selection of equipment, such as heat exchangers, evaporators, furnaces, and driers; evaluation of equipment to determine optimum alternatives; and theoretical analysis of problems in heat transfer in proposed equipment for new applications. Other typical heat transfer problems encountered involve reboilers, inert gas generators, direct fired production furnaces, and indirect fired retorts.

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Successful applicant will assist in the application of high energy radiation in initiating chemical reactions and in altering properties of materials. Desirable background will include broad knowledge of accelerators, radioisotopes and nuclear reactors. Should be familiar with and able to develop unique manipulators, materials handling devices, economic shielding techniques, and remote controlling and maintenance techniques. Work will require familiarity with radiation hazards, employee protection methods, and use of radioactive tracers used in research and manufacture.

PROCESS ANALYSIS AND EVALUATION

Duties are: Assistance in the preparation and analysis of basic information for design of operating units and supporting facilities in order to obtain optimum performance with minimum investment and operating costs; preparation of flow sheets; evaluation of process alternatives; selection and approximate sizing of equipment; and establishment of heat and material balances. Position requires five or more years of experience in equipment selection, economic evaluation of processes, and development of information for design of industrial facilities.

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This position requires extensive knowledge of fine particle technology and broad experience with size reduction operations and equipment. The successful applicant will be called on to provide competent technical advice on: grinding in liquid media, dust collection and screening, size classification, equipment evaluation and selection, modification of existing equipment for unusual and special grinding problems, and handling of finely ground materials. Problems encountered will provide opportunity for developing new concepts and extending the known technology.

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ACADEMIC POSITION—Chemical engineer, age forty or younger, graduate degree, active member A.I.Ch.E., to fill vacancy in department of midwestern university for fall 1956. Research and consulting encouraged. Rank and salary depending on qualifications. Give full particulars, including personal data, training, experience, references. State salary requirements. Include recent snapshot. Box 6-2.

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ACADEMIC POSITION—Chemical Engineer, Ph.D. Age 37. Seeks position as department head or full professor. Eleven years' teaching, industrial, research, and administrative experience. Publications. Excellent references. Twelve-month basis preferred. Please give salary available. Box 9-2.

CHEMICAL ENGINEER—Ph.D. 1938. Comprehensive process engineering experience. Specialist in solvent extraction. Broad administrative and supervisory experience. Recent nuclear and creativity studies. Available for more responsible position with engineering, research, or processing organization. Box 10-2.

CHEMICAL ENGINEER—Ph.D. Twenty years' experience in teaching and industry. Desires responsible position in development or process engineering. Box 12-2.

CHEMICAL ENGINEER—B.Ch.E., bilingual, nine years' research and development in oil and gas. Five years' process and project engineer oil refineries. Desires assignment in Europe. Box 13-2.

CHEMICAL ENGINEER—M.Ch.E., Sigma Xi, age 35, married. Broad, successful experience in process engineering and production of organic chemicals and plastics. Seeking challenging responsible position in process development with progressive organization. Box 14-2.

GRADUATE CHEMICAL ENGINEER desires sales or production position in Southwest. Eight years' experience, married, age 32, B.S. Texas A. & M. Box 15-2.

CHEMICAL ENGINEER—Age 35. Seeks active position in nuclear development design. Experience includes responsible charge of process design and development projects. Graduate of Oak Ridge School of Reactor Technology. Five figures. Box 16-2.

CHEMICAL ENGINEER—M.S.Ch.E. 6½ years' responsible experience in pilot plant process development, installation of new processes, process improvement and trouble-shooting. Desires supervisory or administrative position in development or production engineering. Age 30, veteran, married. Box 17-2.

CHEMICAL ENGINEER—B.Ch.E. Five years' diversified experience in research and development as group supervisor and project engineer in connection with product improvement and production trouble-shooting. Desire challenging position in production, development, or pilot plant work. Veteran, married. Box 18-2.

CHEMICAL ENGINEER—B.S.Ch.E. Age 30. Desires "Part Time" chemical engineering work at home. New York metropolitan area. Box 19-2.

RESEARCH-DEVELOPMENT ENGINEER—M.S.Ch.E. 1949. Six years' experience in process and equipment development; project engineering; technical report writing; supervision. Publications. Desire responsible position in process or product development. Present salary $7,600. Age 27, family, veteran. Box 20-2.

Miscellaneous

FOR SALE — CHEMICAL ENGINEERING PROGRESS, 1947-1953 inclusive, seven bound volumes, $70.00. Box 23-2.

DIRECTIONS FOR USE OF CLASSIFIED SECTION

Advertisements in the Classified Section of Chemical Engineering Progress are payable in advance at 20¢ a word, with a minimum of four lines accepted. Box number counts as two words. Advertisements average about six words a line. Members of the American Institute of Chemical Engineers in good standing are allowed one six-line Situation Wanted insertion (about 36 words) free of charge a year. Members may enter more than one insertion at half rates. Prospective employers and employees in using the Classified Section of Chemical Engineering Progress agree that all communications will be acknowledged; the service is made available on that condition. Boxed advertisements are available at $17 a column inch. Size of type may be specified by advertiser. Answers to advertisements should be addressed to the box number, Classified Section, Chemical Engineering Progress, 25 West 45th Street, New York 36, N. Y. Telephone COlumbus 5-7330. Advertisements for this section should be in the editorial offices the 15th of the month preceding publication.

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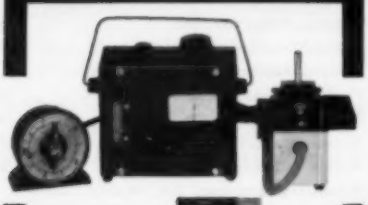

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MARKETING

W. J. F. Francis has been appointed vice president in charge of sales for American Potash & Chemical Corp. with offices in Los Angeles. He has been general sales manager, western division, since 1952, when he joined the firm from Pennsylvania Salt Manufacturing Co., Tacoma, Wash.

Robert E. Wilkin of Hooker Electrochemical Co., Niagara Falls, N. Y., is elected to the company's board of directors. He was also named vice-president and director of sales. He joined Hooker in 1936 as sales manager of fine chemicals. In 1949 he was made general sales manager, and in 1953 vice president and general sales manager.

James E. McCabe has been appointed director of market planning of the chemical division of Merck & Co., Rahway, N. J.

Singmaster & Breyer, N. Y., advances **John A. Hufnagel** to fill the newly-created position of sales manager.

Necrology

William S. Turner, 45, manager of Industrias Quimicas de Mexico, Morelia, Mich. Mexico, S. A.

Harold S. Kendall, 62, assistant to the president of Dow Chemical Co., Midland, Mich.

Donald Bradner, 64, research consultant, self-employed, Washington, D. C.

William J. Murphy, vice president in charge of sales and a director of American Potash & Chemical Corp, N. Y.

Marshall L. Hough, 56, president of Darling Valve & Manufacturing Co., of Williamsport, Pa. For the past 20 years president and treasurer of Darling, Mr. Hough was widely known throughout the industry.

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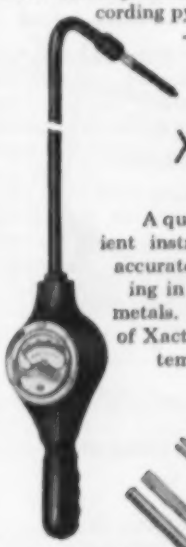

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INDEX OF ADVERTISERS

	Page
A	
Ace Glass, Inc.	98
Acme Coppersmithing & Machine Co.	53
Aerofin Corp.	12
Air Products Inc.	57
Aldrich Pump Co., The	99
Allis-Chalmers Mfg. Co.	23
Alsop Engineering Corp.	89
American Hard Rubber Co.	22
Ayerst Laboratories	74
B	
Baker Perkins, Inc.	17
Beckman, Inc., Arnold O.	16
Bendix Aviation Corp.	96
Bethlehem Foundry & Machine Co.	79
Bloch Industries	87
Blaw-Knox Co., Buflovak Equip. Div.	40
Brookfield Engineering Laboratories, Inc.	87
Brown Fintube Co.	*Inside Back Cover*
C	
Carlson, Inc., G. O.	38
Central Scientific Co.	10
Chicago Bridge & Iron Co.	83
Cleveland Wire Cloth & Mfg. Co., The	36
Climax Molybdenum Co.	27
Condenser Service & Engineering Co., Inc.	28
Consolidated Electrodynamics Corp.	4
Cooper Alloy Corp.	85
Crane Company	71
Croll-Reynolds Co., Inc.	111
D	
Dow Corning Corporation	102
Downingtown Iron Works, Inc.	81
Duraloy Co., The	86
Durametallic Corp.	74
Duriron Co., Inc.	33
E	
Eaton-Dikeman Co.	88
Eco Engineering Co.	92
Elmco Corporation	26
Elliott Co.	89
Ertel Engineering Corp.	99
F	
Fansteel Metallurgical Corp.	91
Ficklen, III, Jos. B.	109
Floridin Co.	95
Fluor Corp., The	64
Foxboro Co., The	35
G	
Garlock Packing Co.	84
General American Transportation Corp. Turbo Mixer Div.	51
Girdler Company, The	31
Goodall Rubber Co.	37
Gordon Co., Cloud S.	109
Great Lakes Carbon Corp., Electrode Division	63
Dicalite Div.	45
Gump Company, B. F.	3
H	
Houdry Process Corp.	46
I	
Industrial Filter & Pump Mfg. Co.	60
Ingersoll-Rand Co.	11
J	
Jet Propulsion Laboratory	105
Johns-Manville	18, 19, 54
L	
Lapp Insulator Co.	41
Leslie Co.	20
Lummus Co.	59
M	
Mercoid Corp., The	110
Metals Disintegrating Co., Inc., Pulverizing Mach. Div.	7
Milton Roy Company	34
Misco Fabricators, Inc.	101
Mixing Equipment Co., Inc.	*Back Cover*
N	
Nagle Pumps, Inc.	103
National Carbon Co.	48
Newark Wire Cloth Co.	82
Niagara Blower Co.	32
Nordstrom Valve Div., Rockwell Mfg. Co.	8, 9
P	
Patterson-Kelley Co., Inc.	69
Philadelphia Gear Works, Inc.	91
Philbrick Researches, Inc., George A.	13
Pittsburgh Coke & Chemical Co.	29
Potter Aeronautical Co.	25
Process Filters, Inc.	77
Proctor & Schwartz, Inc.	62
Pulverizing Machinery Div., Metals Disintegrating Co., Inc.	7
Pyrometer Instrument Co., The	109
R	
Ranney Methods Water Supply, Inc.	90
Read Standard Corp.	6
Reinhold Publishing Corp.	101
Renneburg & Sons Co., Edward	103
Republic Flow Meters Co.	30
Rockwell Mfg. Co., Nordstrom Valve Div.	8, 9
S	
Schutte & Koerting Co.	93, 97, 99
Shriver & Co., Inc., T.	100
Sier-Bath Gear & Pump Co.	58
Sperry & Co., D. R.	80
Spray Engineering Co.	100
Spraying Systems Co.	97

Page

Stephens-Adamson Mfg. Co. 24, 97
Sturtevant Mill Co. 39
Struthers Wells Corp. 21

T

Taylor & Co., W. A. 76
Tube Turns Plastics, Inc. 88
Turbo Machine Co. 75
Turbo-Mixer Div. 51

U

Union Carbide and Carbon Corp.
National Carbon Co. 48
U. S. Electrical Motors, Inc. 93
United States Gasket Co. 44
U. S. Industrial Chemical Co. 43
U. S. Stoneware Co. 44F

V

Vanton Pump & Equipment Corp. 73
Vulcan Copper & Supply Co., The
Inside Front Cover

W

Whitlock Mfg. Co. 42
Wigton-Abbott Corp. 78
Wiley & Sons, Inc., John 102
Wilmad Glass Co. 92
Worthington Corp. 14, 15

Y

York, Inc., Otto H. 56

C.E.P. Advertising Offices

New York 36—Lansing T. Dupree, Adv. Mgr.; John M. Goede, Asst. Adv. Mgr.; Paul A. Jolcuvar, Dist. Mgr.; Donald J. Stroop, Dist. Mgr.; 25 W. 45th St., Columbus 5-7330.

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news and notes of A.I.Ch.E.

Nominating Committee will be headed by B. F. Dodge, past president, who was appointed by Council at its January meeting . . . It might not be amiss at this time to review briefly for the membership the functions of the Nominating Committee and to preview its task in 1956 . . . Provisions for the Nominating Committee as passed a few years ago by the members specify that the committee be composed of at least five Members or Associate Members of the A.I.Ch.E. . . . There may be a greater number and has been in the past . . . Committee chairmen have tried to obtain on the Nominating Committee a geographical balance that would tap the best available men from all parts of the United States . . . Nor is the geographical representation neglected in nominating officers and directors, as the committee is well aware of its responsibility in this regard . . . Suggestions made by Local Sections and individuals are all carefully weighed and possible candidates are apprised of the requirements of office including their expected attendance at Council meetings . . . When the slate is completed, the A.I.Ch.E. office is notified and suitable publicity on the candidates is given in *Chemical Engineering Progress* . . . Local Sections contemplating the nomination of a favorite son by petition ought to be well aware of the timetable involved . . . The constitution calls for the nominating ballot to be in the Secretary's office not later than seven weeks prior to the Annual Meeting . . . However, the Nominating Committee has been asked by a Council by-law to bring in their nominees eighteen weeks prior to the Annual Meeting in order that the candidates' records may be seen by the membership early in the year . . . Last year, for instance, most of the candidates were publicized in the July issue, the ballot going out for action about October 1 . . . However, the deadline for nomination by petition is still the constitutional seven weeks, or this year October 5 . . . May I take this opportunity to pass on to the Local Sections the information that the committee this year will try to report on its choice of candidates as early as did the committee in 1955, so that once again the July issue may contain pictures of most of the candidates . . . This means that petitions, biographical data, pictures, etc., ought to be in A.I.Ch.E. headquarters no later than June 15 in order to give adequate publicity to any candidate nominated by petition . . . The last possible date for nominations by petition to be received in this office will be October 5; however, there will be little opportunity for publicity at this late date . . . We shall have the election ballot standing in type and waiting for last minute additions to be made in time to mail it to the members no later, we hope, than October 15 . . . It seems important to me, as Secretary, that these facts be given the membership so that the nominating procedure may be just as fair as possible to everyone who has agreed to run for Council . . . A.I.Ch.E. has always been fortunate in having a high caliber of person available for office . . . We believe that decisions affecting chemical engineering in the next ten years are going to be of an extremely critical nature and that the burden that will be placed on these men will not be light . . . **How Many Vote?** Last year, out of the total of 14,691 ballots mailed, there were returned in time for counting 6,870, or 46.07% . . . . **The Harris-Fulbright Bill** came in for discussion by both the Executive Committee and Council . . . The Dallas Section presented a resolution to Congress in favor of the passage of this bill and also sent notice of its action to other Local Sections . . . This was examined carefully by the Executive Committee in the light of A.I.Ch.E.'s legal and historic position in relation to legislation . . . Consensus was that nothing be done to curtail free expressions of Local Sections on this matter . . . However, it was decided that as a national organization we take no position on the Harris-Fulbright Bill and Council agreed with the conclusions reached by the Executive Committee.

F.J.V.A.

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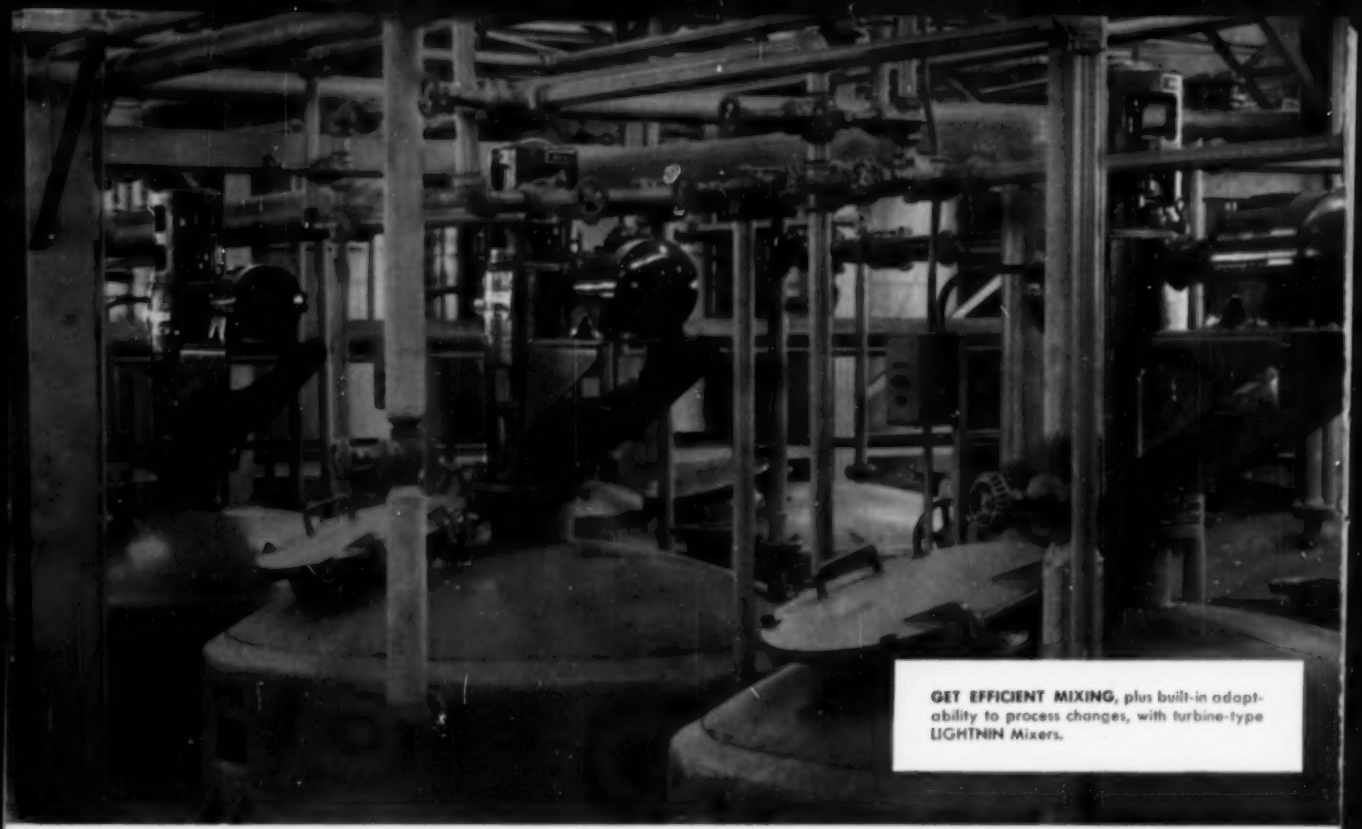

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On complex mixing jobs, pilot runs at MIXCO quickly find the impeller-to-tank diameter ratio and input power that will produce the optimum fluid regime most economically. Scale-up is *guaranteed accurate.*

Mechanical economy

Your mixer investment goes into equipment that is mechanically up-to-the-minute. Hundreds of *standard* LIGHTNIN power-speed combinations (interchangeable in many models); widest possible choice of in-stock materials and interchangeable components, give you assurance of correct application, smooth running, and flexibility when you need it.

For fluid mixing that does what you want it to do, call in your LIGHTNIN Mixer representative. (He's listed in Chemical Engineering Catalog.) Or write us direct.

"Lightnin' Mixers"

MIXCO fluid mixing specialists

Left: **ANY TANK,** *regardless of size or shape, can be fitted with a* LIGHTNIN *Mixer for correct mixing.* ***Right:*** *Make any open tank an effective mixing unit, with a* LIGHTNIN *Portable Mixer. Thirty models.*

FOR LATEST MIXING INFORMATION and full description of LIGHTNIN Mixers, send for these helpful bulletins:

- ☐ B-102 Top or bottom entering; turbine, paddle, and propeller types: 1 to 500 HP
- ☐ B-103 Top entering; propeller types: ¼ to 3 HP
- ☐ B-108 Portable: ½ to 3 HP
- ☐ B-104 Side entering: 1 to 25 HP
- ☐ B-112 Laboratory and small-batch production types
- ☐ B-109 Condensed catalog showing all types
- ☐ B-111 Quick-change rotary mechanical seals for pressure and vacuum mixing
- ☐ B-107 Data sheet for figuring mixer requirements

Check, clip, and mail with your name, title, company address to:

MIXING EQUIPMENT Co., Inc., 199-b Mt. Read Blvd., Rochester 11, N. Y.

In Canada: Greey Mixing Equipment, Ltd., Toronto 10, Ont.